A FEASIBILITY STUDY ON A LOW GROUND PRESSURE SPRAYING VEHICLE

G.W. Cussans and P. Ayres

ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford OX5 1PF

Summary During the winter 1977/78 a lightweight low ground pressure vehicle equipped with a hydraulic nozzle sprayer was examined for its suitability for use on wet soils to apply herbicides for the control of autumn germinating weeds. Herbicides used included paraquat, chlortoluron, isoproturon, clofop-isobutyl and a mecoprop/ioxynil mixture and these were applied at volume rates of 60-180 l/ha and forward speeds of 6.7-20 km/h. All herbicides were applied at their manufacturers recommended dose rates with the exception of clofop-isobutyl which was applied at three quarters of its recommended rate.

The machine was assessed in respect to its ability to travel on to wet soils, handling characteristics, stability and herbicide performance. The study suggests that, although herbicide performance at reduced volume may require further examination, the use of such vehicles to apply herbicides during the autumn and winter could be commercially successful.

INTRODUCTION

In recent years there has been a marked increase in the area of winter sown crops of cereals and oil-rape, both nationally and on individual farms. This trend has in turn, led to a growing need to spray these crops during the autumn and winter period. This need has arisen because certain chemicals are most effective applied at this time and because early removal of many weeds may be necessary to ensure maximum crop yield (Hubbard, Livingstone and Ross, 1976; Wilson and Cussans, 1978). However, many soils are so wet during much of this period that spraying with conventional tractors may be impossible because of the weight of the loaded sprayer, or possible only at the expense of severe wheel damage to the crop and soil.

An additional factor, in recent years, has been a desire to reduce spray liquid volumes of diluent, so as to increase the speed of spraying. This has been achieved by rotary atomisers in many experiments (Cussans and Taylor, 1976) but there has also been a great interest in re-examining the recommendations for hydraulic nozzle applications.

Finally, it has been suggested (Byass and Lawrence, 1976; Cussans and Taylor, 1976) that an alternative spraying vehicle to the conventional tractor could allow faster forward speeds and, thus, further increase spraying efficiency.

It was considered that the situation had reached something of an impasse; engineers were unlikely to develop specialised vehicles until the technical feasibility had been demonstrated, but this could not be accomplished without suitable vehicles. Accordingly it was agreed between the Weed Research Organization, the National Institute of Agricultural Engineering and I. Rutherford, ADAS liaison officer at the latter institute that we should embark on a simple feasibility study, using the most suitable vehicle commercially available.

The work described here employed the 'Argocat 8', a vehicle well established as an all-terrain personnel carrier, amphibious and exerting very low ground pressure. The vehicle had also been used for spraying, mainly small-scale specialist operations.

There was insufficient time to construct a rotary atomiser, controlled drop application (CDA) machine, to operate at 20-40 l/ha. Accordingly a conventional sprayer was built and the study explored the use of hydraulic nozzles at volumes from 60-180 l/ha.

A further experiment, which will be reported elsewhere, studied the effects of wheelings on soil and on crop growth. This experiment compared a conventional tractor, the 'Argocat 8' and a lightweight track layer the 'Highland Garron' on which was mounted a granular herbicide distributor.

METHOD AND MATERIALS

The vehicle used in the feasibility study, the 'Argocat 8', was powered by a two stroke twin cylinder engine and skid-steered by disc brakes fitted to the output shafts of the differential. The body, made of high impact polyethylene plastic was mounted on a flexible chassis and supported by 8 wheels all of which were driven. Each wheel was fitted with a low pressure tubeless tyre (30 mm x 50 mm) inflated to approximately 0.14 bars.

The sprayer components were mounted on a metal frame in the rear compartment of the vehicle. The frame was bolted to the chassis and attached to the body on rubber blocks. The spraying equipment comprised a standard Evrard 9 m boom and diaphram pump, and a 110 l. capacity glass fibre tank. Power to drive the pump was supplied by a 6 hp petrol engine. Liquid from the spray tank was pumped to a control unit which incorporated the main on/off tap, a three way manifold with independent taps for each section of the boom, a bypass valve for the recirculation of the spray solution and a pressure regulating valve. Spray liquid from the control valve was fed to a manifold on each of the three main sections of the boom. Each of the eighteen spray nozzles on the boom were then fed independently from these manifolds.

The spray nozzles, manufactured by 'Spraying Systems', incorporated a non-drip diaphram and 50 mesh filter. The fan nozzles used in this study were Spraying Systems 'Teejets' 8002 and 8003.

Table 1 gives the throughput of the nozzles in a standard laboratory test and on the sprayer, and also the coefficient of variation and range of output across the boom.

Table 1

Nozzle calibration details

Nozzle size	Mean throughput in mls/min at 2.1 bars		C V across boom	% Range
	Lab test	Sprayer		
8002	646	652	1.8	-3.4 to +2.5
8003	967	973	1.5	-2.4 to +3.4

Speed control of the vehicle was by a twist grip throttle and was monitored by an electronic perception tachometer.

Herbicides used in this study (Table 2) were all applied at their recommended dose with the exception of clofop-isobutyl which was applied at three quarters of the recommended rate. At the five black-grass (Alopecurus myosuroides) infested sites, Stratton Audley, Chesterton, Compton, Quainton and Sarsden small, randomly selected, areas were left as unsprayed controls. In June all the black-grass heads were counted in a number of quadrats (0.1 m^2) selected at random in these areas and in adjacent treated areas. From this data estimates of the reduction in black-grass heads were obtained.

Crop yield was assessed at one site (Stratton Audley) where the mature barley was removed from m^2 quadrats on sprayed and unsprayed areas. The samples were threshed with a small plot thresher, weighed, dried, cleaned and sieved for the removal of trash and grain < 2.0 mm and then re-weighed. From these data yield of clean grain > 2.0mm at 85% d.m. was determined.

RESULTS AND DISCUSSION

1. Traffic on wet soils

Table 2 gives details of sites which were sprayed during autumn 1977 to early spring 1978. Table 3 gives details for four of the sites where it was possible to make more complete records. The machine operated across these sites, a total of 35 ha of generally difficult land, without trouble and without obvious wheel markings.

The soil compaction measured by sheer vane (Table 3) showed that the top 8.0 cm of soil was affected by wheeling, although effects were small.

On most sites (the possible exceptions being Begbroke, Compton and Sarsden) we considered that spraying with a conventional wheeled tractor would not have been possible without leaving unacceptably damaged wheel tracks. At the worst sites (Northfield, Quainton and Stratton Audley) it seems unlikely that a trailed sprayer

Table 2

Low ground pressure vehicle-herbicide application details

Site	Crop	Area treated ha	Herbicide	Vol. rate l/ha	Speed km/h	Date	Weeds	Growth stage
Begbroke	-	2.0	Paraquat	60	13	16 Nov. 1977	Various	Seedlings - tillering
Stratton Audley	Winter barley	6.5	Chlortoluron	60	13	18 Nov. 1977	Black-grass	2-3 leaves
Chesterton	Winter barley	i 6.5	Isoproturon	60	20	1 Dec. 1977	Black-grass	2-3 leaves
		ii 3.0	"	60	20	1 Mar. 1978	"	Fully tillered
Buckland	-	2.8	Paraquat	60	20	28 Nov. 1977	Various	Seedlings - tillering
Compton	Winter wheat	2.8	Chlortoluron	60	20	20 Dec. 1977	Black-grass	2-3 leaves
Northfield	Winter wheat	6.0	Difenzoquat	180	6.7	6 Mar. 1978	Cultivated Oats	Tillering
Quainton	Winter wheat	i 1.2	Chlortoluron	60	20	7 Mar. 1978	Black-grass	Well tillered
		ii 0.6	Clofop isobutyl	60	20	11 Apr. 1978	"	" "
		iii 1.8	Isoproturon	60	20	11 Apr. 1978	"	" "
Goddington	Winter wheat	0.6	Mecoprop/Ioxynil	180	6.7	10 Mar. 1978	Broad-leaved weeds	Established
Sarsden	Winter oats	i 0.4	Clofop isobutyl	60	20	17 Apr. 1978	Black-grass	Well tillered
		ii 0.4	" "	120	10	17 Apr. 1978	"	" "
		iii 0.4	" "	180	6.7	17 Apr. 1978	"	" "

could have been used at all without the tractor becoming stuck.

Table 3

Soil details at time of herbicide application

Site	% Soil moisture (15 cm)	Soil description		19 mm sheer vane assessment (Kpa) Wheeled	Unwheeled
Stratton Audley	24.2	Mottled grey brown clay loam to 30 cm over clay or clay loam to 70 cm over bright grey and brown mottled clay	a	13.72	8.00
			b	27.92	18.96
			c	48.08	49.52
Chesterton	17.6	Brown clay loam with limestone fragments, over limestone	a	18.2	8.6
			b	35.3	26.6
			c	48.9	43.0
Compton	23.3	Free drained calcareous silt loam with flints over chalk	a	18.5	12.9
			b	38.2	32.8
			c	49.3	43.7
Buckland	-	Imperfectly drained clay loam over calcareous clay	a	29.3	22.7
			b	56.0	58.2
			c	66.3	64.7
Northfield	48.0*	A greyish brown ocherous mottled clay loam to clay top soil, overlying clayey Head over Gault clay			

a = 2.8 cm b = 8.0 cm c = 15.6 cm *Taken to a depth of 5 cm

At one site, Buckland, soil built up on the tyres to considerable depth. This was regarded as cause for concern at the time although it never reached the stage of interfering with the performance of the machine. This site differed from the others in two respects; it was sprayed just as a frost left the soil and there was very little foliage present, most of the other sites had a good degree of leaf cover from crops.

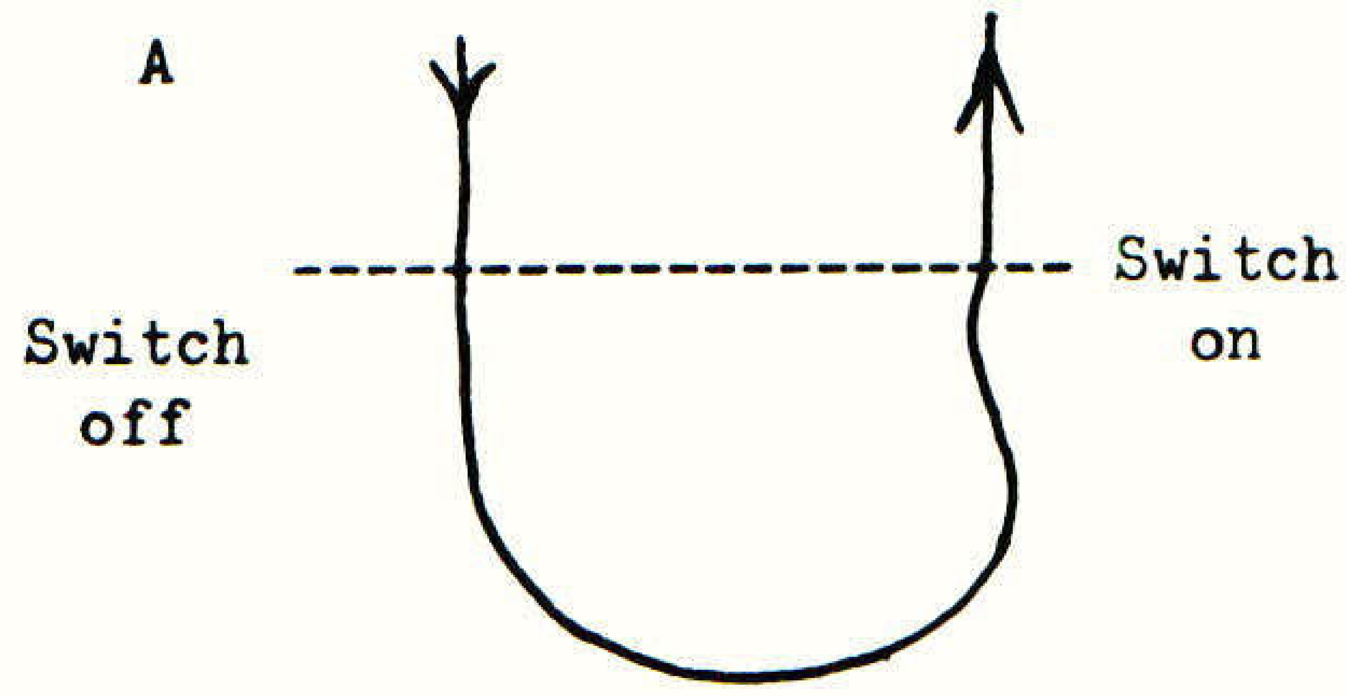
2. Handling characteristics

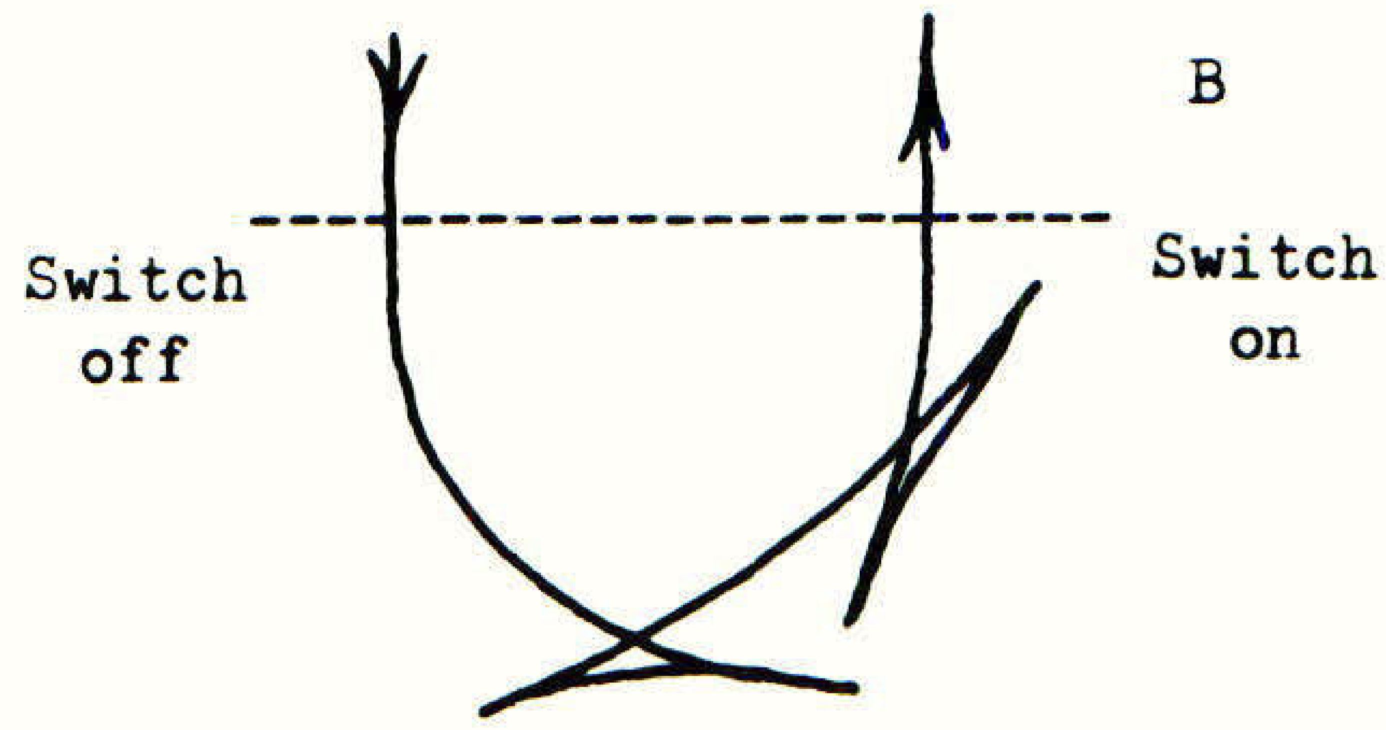
Straight spray runs were trouble free at spraying speeds of 7 to 20 km/h. The vehicle tracked straight, needing very little corrective steering. Although some practice was needed to maintain constant speed with the twist grip throttle, timings taken during actual spray runs indicated that correct speeds were being achieved.

The sprayed areas were carefully marked out with flags, so that the operator always had a line of at least two flags to line up on. We considered that very careful marking out was necessary but this was more a function of the high spraying speeds used than of the steering system. At one site it was possible to use a "tram line" system for some runs only (because our boom width did not coincide with the farmers). It was very noticeable that the 'tram line' runs were more relaxed than those depending on a line of sight between flag markers.

In contrast to the trouble free handling on straight runs, manoeuvre on headlands was more difficult. We have attempted to analyse our own behaviour on headland turns with a conventional tractor and the 'Argocat'.

With the former, turning is simple and can be carried out at full spraying speed (6-8 km/h), usually in a headland on two boom widths. The turn takes the form of a U, with the final part of the U given a 'wobble' to allow final correction (Diagram A). In contrast, with the Argocat we allowed three boom widths (27 m) of headland because of the skid-steering and made a more elaborate 5 point turn (Diagram B).





In practice the final 'wobble' to get into line proved the most difficult part, and despite considerable care and practice it was occasionally necessary to make another shunt to get into line. High speed spraying at 20 km/h exacerbated this problem; the initial 27 metre had to be straight to allow the machine to build up to full spraying speed.

Good, well adjusted brakes make manoeuvring more precise. However, this is the weakest point of the skid steering system employed on the 'Argocat'. Precise manoeuvre was neither easy or instinctive and the loss of power resulting from braking one output of the engine differential made manoeuvring more difficult and speed control almost impossible.

3. Stability

The stability of both the ride and the boom was good even at the relatively high spraying speeds employed. The 9 m boom was linked directly to the sprayer with the only shock absorption being provided by small rubber mounting blocks. However, boom stability compared very favourably with that of conventional sprayers operating at much lower speeds.

4. Herbicide performance

On sites where detailed assessments were conducted (Table 4) the herbicides gave satisfactory levels of weed control although at some sites no comparison with a higher volume rate is available. At Chesterton, in the presence of a vigorous crop of winter barley, more than 96% reduction in black-grass heads was achieved with both early and late post-emergence applications of isoproturon. Good control (94%) of black-grass with isoproturon was also achieved at Quainton. At this site, but on a different replicated experiment 200 m away, isoproturon applied at a volume rate of 225 l/ha at the same dose and on the same date gave 88% control. Control with chlortoluron was less effective at this site than at either Stratton Audley or Compton but this is probably due to the later date of application by which time the black-grass was well tillered.

The three quarter dose rate of clofop-isobutyl gave 89% reduction in black-grass heads at Quainton and, at Sarsden, it was as good when applied in 60 l/ha at a forward speed of 20 km/h as it was 180 l/ha at 6.7 km/h. The better control obtained at 120 l/ha cannot be explained with the limited data available.

The results at Stratton Audley were particularly noteworthy. This site was wet when sprayed in November but shortly afterwards it became, and remained for months, extremely wet with patches of surface water showing for prolonged periods. The crop of winter barley, which was well grown and vigorous at spraying, made little growth till spring. Its overall appearance was yellowed and poor with conspicuous plant mortality and chlorosis of the survivors in the wettest patches. A. myosuroides flourished in the unsprayed areas and the yield of clean grain from these areas was 2.45 t/ha. From the treated areas we obtained 4.40 t/ha.

This is of interest for two reasons. It provides a good, albeit an extreme, example of the need for lightweight low ground pressure spray vehicles. Had we not applied the chlortoluron it seems very unlikely that a conventional wheeled sprayer could have treated the area before April. This experience also suggests that chlortoluron can be safe and effective in these rather extreme conditions although such operations must be viewed with some caution.

Table 4

Black-grass control obtained with herbicides applied at low volumes and high forward speeds

Site	Herbicide	Vol rate l/ha	Speed km/h	% control
Stratton Audley	Chlortoluron	60	13	88
Chesterton	Isoproturon	60	20	i 96
				ii 97
Compton	Chlortoluron	60	20	89
Quainton	Chlortoluron	60	20	74
	*Clofop-isobutyl	60	20	89
	Isoproturon	60	20	94
Sarsden	*Clofop-isobutyl	60	20	84
		120	10	96
		180	6.7	82

*Applied at ¾ of recommended dose

At all other sites only subjective assessments of herbicide performance are available. Weed kill from applications of paraquat at Begbroke and Buckland appeared even and broad-leaved weed control with the mecoprop/ioxynil mixture at Goddington was also satisfactory. At Northfield the site was subsequently re-sprayed because the amount of difenzoquat applied at the first date was not sufficient to control the large cultivated oats present.

CONCLUSIONS

A feasibility study of the type described here must, by its very nature, create as many questions as it answers. In particular we believe that herbicide performance at reduced water volumes needs more prolonged and careful study. However, this work and other work elsewhere does suggest that this is a subject where considerable advances are possible.

Our experience with the vehicle has shown that all the requirements of autumn and winter spraying can be met. It is possible to spray land when it is far too wet for conventional equipment and to increase forward speed without excessive boom bounce.

One concern is that the skid steering system makes headland manoeuvring difficult and could make spraying in a curved track almost impossible. This problem could be overcome by the use of differential clutch and brake steering and such a modification has already been developed. A bigger payload would also be an improvement but this presents commercial, manufacturing problems rather than fundamental engineering problems. Finally, increase in forward speeds, although entirely feasible, should be accompanied by modifications to avoid undue strain on the driver. Improved bout marking and sprayers which adjust concentrate delivery to the forward speed are two examples.

Despite these cautions we believe that lightweight, low ground pressure, high speed sprayers, and the implications they have for application technology, will increase significantly the options open to farmers.

Acknowledgements

We would like to thank Mr Geoff Edmunds, All Terrain Vehicles Ltd, Newport, Gwent, who provided the vehicle and has been a constant source of help and advice. We would also like to thank Mr I. Rutherford, ADAS Liaison Unit, Silsoe, whose encouragement and support made this project possible. Thanks are also due to Messrs. R.W. Foddy and A.M. Bland, WRO workshop for the building and fitting of the sprayer, Mr. R. Palmer, Heygate Chemicals Ltd for the loan of sprayer components, Miss J.E. Birnie and Mr R.A.P. Denner for their assistance with the field work, Messrs. R. Webster and J. Hazelden, Soil Survey for the soil descriptions and the farmers who provided the sites.

References

BYASS, J.B. and LAWRENCE, D.C. (1976) The scope for the use of controlled drop application (CDA) on large cereal-growing farms. Proc. British Crop Protection Conference - Weeds, 2, 363-368.

CUSSANS, G.W. and TAYLOR, W.A. (1976) A review of research on controlled drop application at the ARC Weed Research Organization. Proc. British Crop Protection Conference - Weeds, 3, 885-894.

HUBBARD, K.R., LIVINGSTON, D.B. and ROSS, B.L. (1976) Chemical control of *Alopecurus myosuroides* in winter cereals. Proc. British Crop Protection Conference - Weeds, 1, 63-70.

WILSON, B.J. and CUSSANS, G.W. (1978) The effects of herbicides, applied alone and in sequence, on the control of wild oats (*Avena fatua*) and broad-leaved weeds, and on yield of winter wheat. Ann. appl. Biol., 89, 459-466.

Proceedings 1978 British Crop Protection Conference - Weeds

LOGISITICS OF SPRAYING WITH REDUCED VOLUMES OF SPRAY AND HIGHER VEHICLE SPEEDS

H.J. Nation

National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford. MK45 4HS

Summary A method has been developed to simulate a days spraying using a mathematical model written as a program run in a digital computer. It is possible to investigate rapidly the likely effect on overall working rate of variations in any one or two of various parameters. The results presented illustrate the effects of varying application rate, spraying speed, boom length and field size.

INTRODUCTION

The possible effects on the overall concept of the sprayer of new spraying techniues such as the use of low volumes and of the higher spraying speeds possible with suspended vehicles and better boom designs may not be entirely apparent. For example, the optimum relationship between size of the boom and size of the tank is an important matter. A major area of concern to the farmer or spray contractor is the management of the spraying operation. With a mathematical model of a typical spraying operation these effects may be rapidly investigated for particular spraying situations.

METHODS

The basic model

The spraying operation which is simulated consists of one days work. Provided that the size of field is not one of the variables to be investigated the spraying is repeated over and over again throughout the day in fields of the same size. The model caters for different methods of refilling the sprayer, either at the farm or at the field gate or from a bowser moved along the field headland. A number of swaths around the field can be sprayed before starting parallel swaths. The sprayer tank can be refilled when it is completely empty or at the beginning of the swath in which it would otherwise run out. A refilling rate is stipulated from which the refilling time is calculated and an allowance is also made for addition of chemical. At the completion of each field a stipulated time is allowed to represent the move from this field to the next.

Throughout the progess of the simulation time checks are made when the sprayer tank is empty or when a field change occurs and the option exists of making time checks also at the end of each swath around the field and at the end of each parallel swath. At appropriate times allowances can be made for meal breaks, if these have been stipulated. Spraying is concluded if the given days length has

**APPLICATION RATE, L/HA.	20.000	BOOM LENGTH, M.	20.000	MINIMUM PART OF SWATH	0.000
**"LONG" SIDE OF FIELD, M.	400.000	"SHORT" SIDE OF FIELD, M.	300.000	FIELD TO FARM, KM.	0.000
**SPRAYER CAPACITY, L.	1200.000	BOWSER CAPACITY, L.	10000.000	SPRAYING SPEED, KM/H.	6.000
**EMPTY SPEED IN FIELD, KM/H.	15.000	LOADED SPEED IN FIELD, KM/H.	12.000	ROAD SPEED, KM/H.	25.000
**MAINTENANCE TIME, MIN.	0.000	CHEMICAL MIXING TIME, MIN.	6.000	TURNING PAUSE TIME, MIN.	0.050
**REFILL PAUSE TIME, MIN.	5.000	NEW FIELD TIME, MIN.	20.000	BOWSER REFILL TIME, MIN.	0.000
**BREAKFAST TIME, H.	0.000	BREAKFAST BREAK, MIN.	0.000	LUNCH TIME, H.	0.000
**LUNCH BREAK, MIN.	0.000	TEA TIME, H.	0.000	TEA BREAK, MIN.	0.000
**NORMAL DAY LENGTH, H.	9.000	SUPPER BREAK, MIN.	0.000	TOTAL DAY LENGTH, H.	9.000
**LATE SHIFT ALLOWANCE, MIN.	0.000	REFILL MARGIN TIME, MIN.	6.000	PERFORMANCE LIMIT, %	100.000
**FIRST INCREMENT ADDED	25.000	SPEED OR BOOM LENGTH RATIO	0.900	REFILL RATE, L/MIN.	100.000
**SECOND INCREMENT ADDED	2.000	VALVE SWITCH TIME, MIN.	0.000	FIXED TURN TIME, MIN.	0.000

TOTAL AREA SPRAYED IN DAY, HECTARES
****

SPRAYING SPEED, KM/H.	APPLICATION RATE, L/HA.								
	20.000	45.000	70.000	95.000	120.000	145.000	170.000	195.000	220.000	0.000
6.000	72.000	68.800	65.600	62.640	60.000	57.931	54.880	52.960	50.640	0.000
8.000	86.640	81.440	76.960	72.000	70.720	66.880	63.529	60.000	59.360	0.000
10.000	100.960	94.080	86.640	80.160	78.240	72.000	72.000	65.600	62.640	0.000
12.000	110.640	102.880	96.000	88.421	84.000	77.600	72.000	70.720	66.880	0.000
14.000	120.000	108.000	102.240	92.800	89.600	84.000	78.880	73.846	72.000	0.000
16.000	124.960	115.520	107.360	96.000	93.440	84.000	83.360	76.960	72.000	0.000
18.000	132.000	120.000	110.640	102.880	96.000	92.160	84.000	81.440	76.960	0.000
20.000	140.160	130.720	120.000	108.000	100.960	94.720	86.640	84.000	76.960	0.000
22.000	144.000	132.000	120.000	110.640	102.880	96.000	91.520	84.000	82.720	0.000

OVERALL SPRAYING RATE, HECTARES/HOUR
****

SPRAYING SPEED, KM/H.	APPLICATION RATE, L/HA.								
	20.000	45.000	70.000	95.000	120.000	145.000	170.000	195.000	220.000	0.000
6.000	7.950	7.619	7.205	6.821	6.762	6.421	6.054	5.781	5.485	0.000
8.000	9.506	8.976	8.528	8.183	7.670	7.169	6.993	6.808	6.567	0.000
10.000	11.083	10.426	9.356	8.870	8.653	8.271	7.642	7.228	6.881	0.000
12.000	12.161	11.362	10.639	9.727	9.344	8.572	8.187	7.809	7.303	0.000
14.000	13.581	12.099	11.331	10.280	9.890	9.190	8.484	8.155	7.790	0.000
16.000	13.812	12.801	11.910	11.062	10.341	9.679	9.253	8.478	8.157	0.000
18.000	14.932	13.750	12.250	11.234	10.999	9.942	9.672	8.816	8.266	0.000
20.000	15.496	14.468	12.900	12.062	10.950	10.490	9.505	9.317	8.518	0.000
22.000	16.382	15.122	13.359	12.216	11.379	10.912	10.145	9.578	8.893	0.000

Table 1

elapsed. At the end of the days spraying the overall spraying rate is calculated from the total area covered and the time taken.

Collection of data for the model

The development of this mathematical model is proceeding concurrently with the collection of information from typical spraying operations observed with workstudy-type techniques. These observations provide information on the duration of different parts of the spraying operation, for example, turns, filling and refilling, chemical mixing and other causes of lost time. Other methods of calculating the overall spraying rate have been studied, including the well-known Baltin/Amsden formula. In some cases, good agreement has been obtained with the overall spraying rates calculated according to this formula.

Using the model

The model caters for the use of up to ten different values of any two of the main parameters of the spraying operation. These different values are examined in turn so that a maximum of one hundred different runs of the model may be carried out in one run of the program. For the purpose of this report nine values of spraying speed and nine values of application rate were examined making a total of 81 different days of spraying examined in each run of the model but not all the results are given here. The computer took about 30 seconds to complete this work each time. Separate runs of the program were carried out with three different boom lengths, two field sizes and two tank sizes. Time checks were made as frequently as possible and the work for the day brought to a close as soon as possible after the full nine hours of the day's work had elapsed. For all the runs the other quantities remained unchanged and the values used can be seen in the data printed out at the top of Table 1. This shows that no meal breaks were allowed - a relief driver was assumed to be available. The field size used for all runs except one was 12 hectares, the field being 400 metres by 300 metres. In the comparison of field size the alternative field was 48 hectares, each field dimension being double the original. The three boom lengths used were 12m, 16m and 20m. The tank size was 600 l. for all three with a repeat run at 1200 l. for the longest boom. Two further runs compared refilling methods. The main details of the runs are listed in Table 2. At the completion of a computer run two print-outs were provided. One listed the results in detail from all the days worked in that one run of the computer program with actual time taken, number of tank fills, actual area covered and other details. The second print-out consists of summary tables of the total areas worked each day and the overall work rate in ha/h. An example of this summary print-out is given in Table 1.

Table 2

Main variables of the runs

	Boom length, m	Tank size, l.	Field size ha	Field conditions
A	12	600	12	Normal day length, spray remaining in tank.
B	16	600	12	"
C	20	600	12	"
D	20	1200	12	"
E	20	1200	48	"
F	12	600	12	Returning 1.5 km to farm to refill at 100 l/min
G	12	600	12	Returning 1.5 km to farm to refill at 20 l/min

RESULTS

Effect of application rate

A typical set of curves of overall working rate plotted against application rate for two spraying speeds and three boom lengths with the 600 l. tank is shown in Fig. 1. Table 3 shows the increase in working rate, as a percentage, obtained by reducing the application rate from the conventional rate of 200 l./ha, first of all, to about one third, 70 l./ha and then, to 30 l./ha to represent CDA spraying. For example, from this table, the 12 m boom sprayer travelling at 10 km/h and applying 70 l/ha shows an increase in working rate of 52%. Or, taking CDA and assuming it is being applied by a vehicle capable of 18 km/h with a 12 m boom, the output is doubled.

Table 3

Percentage increase in working rate by reducing application rate from 220 l./ha to (i) 70 l./ha, and (ii) 30 l./ha for 12, 16 and 20 m booms, 600 l. tanks and 12 ha fields

Spraying speed km/h	Percentage increase (i)			(ii)		
	12m	16m	20m	12m	16m	20m
6	38	41	54	56	59	78
10	52	61	63	76	93	92
14	56	65	67	88	104	109
18	62	72	75	100	117	121
22	72	79	80	115	125	130

Effect of forward speed

A typical set of curves showing the effect of spraying speed on overall work rate is shown in Fig. 2 for two application rates and three boom lengths. At 220 l./ha increase in speed beyond 14 km/h has very little beneficial effect, whereas the effect continues to higher speeds at the low application rate. In Table 4 is given the percentage increase in working rate obtained by increasing speed from 8 to 18 km/h - a speed increase of 125%. For all boom sizes the effect at the low application rate is double that at the highest application rate. The figures also show that the effect is greater for the smaller booms than for the larger booms.

Table 4

Percentage increase in working rate by increasing spraying speed from 8 to 18 km/h for 3 boom lengths, 600 l. tanks and 12 ha fields

Application rate	Percentage increase		
l./ha	12m	16m	20m
20	64	58	51
45	60	52	42
70	54	45	39
120	45	38	32
170	37	31	29
220	33	31	26

Effects of some other variables

Sprayer tank size and field size can have significant effects on the overall work rate. Some typical results for these two factors are given in table 5 which expresses the percentage increase in working rate obtained by increasing, first, the tank size from 600 to 1200 l. when using a 20 m boom in a 12 ha field and then the field size by four times to 48 ha, at rates of 220, 70 and 30 l./ha. The tank size is most significant when using the conventional rate of 220 l./ha. It is of less significance when applying the low rates of CDA. The effect of increase in field size is much more significant at the CDA application rate than at the conventional or reduced rates.

Table 5

Percentage increase in working rate by (i) increasing tank size from 600 l. to 1200 l. for 20 m boom in 12 ha field, and (ii) increasing field size to 48 ha for 20 m boom and 1200 l. tank, at 3 application rates.

Spraying speed	(i)			(ii)		
km/h	220 l./ha	70 l./ha	30 l./ha	220 l/ha.	70 l./ha	30 l./ha
6	34	16	7	16	16	24
10	35	18	8	20	32	32
14	40	21	13	25	34	43
18	46	24	15	25	36	48
22	48	24	14	24	42	61

Effect of management methods

The above results have been concerned with matters of choice in sprayer selection in relation to the conditions in which it is to be used. It has been assumed that the management of the spraying operation was good, that is to say, water was supplied in the field with a good refilling rate into the sprayer. If management is not good the overall working rate can be seriously affected, particularly at high application rates when more frequent refills of the tank are required than with lower application rates. The percentage reduction in overall work rate by, first, returning to the farm to refill at 100 l./min and, second, refilling there at 20 l./min, at all the application rates examined is listed in table 6 for the working speeds of 8 and 18 km/h. At 20 l./ha the overall working rate is not reduced more than one fifth. At 70 l./ha the output is reduced by about one third but with the high application rate over half the output is lost through the additional travelling and refilling time.

Table 6

Percentage reduction in overall work rate when (i) refilling at farm 1.5 km away at 100 l./min, and (ii) refilling at farm at 20 l./min, compared with refilling from bowser on headland at 100 l./min, for spraying speeds of 8 and 18 km/h, with a road speed of 25 km/h.

Application rate l./ha	(i) 8 km/h	(i) 18 km/h	(ii) 8 km/h	(ii) 18 km/h
20	8	14	16	19
45	16	23	25	34
70	21	29	34	44
120	31	38	44	52
170	35	42	48	56
220	38	46	54	60

Conditions at the end of the day

For these runs the normal day length was stipulated as nine hours. The program was instructed to finish the days spraying at the first opportunity after nine hours had elapsed when either a field was finished or a new field was about to be started or at the end of a swath round a headland or the end of a parallel swath. Thus the actual day length worked will usually be somewhat in excess of nine hours. It is also possible for days of less than nine hours to be worked because the program can anticipate when nine hours would have elapsed by moving to another field with insufficient time to start spraying there and therefore the work for the day is finished on completion of the previous field

With the above finishing conditions there will usually be some spray left in the sprayer tank. An instruction may be given to the program that the sprayer tank should be completely sprayed out. The consequence of this instruction is that at low application rates long days may be worked if the last tank replenishment is a complete refill. The program therefore, has an option to simulate the decision that the operator would make under these circumstances only partially to fill his tank on the last occasion to give him enough spray just to finish the normal days work.

DISCUSSION

This paper has illustrated how a mathematical model of a days spraying can be used as a powerful tool to investigate rapidly the likely effects of the various parameters which can be changed. For the user or adviser this can be helpful as far as matters of choice of sprayer to suit operating conditions and the management of the spraying operation are concerned. From the research point of view such a tool will be of value in identifying those aspects of sprayer use to which more research and development effort should be directed.

In its present form the program deals with one days spraying. It can be envisaged that by suitable elaboration it could include comparisons of costs or take account of weather conditions and, perhaps, soil conditions in relation to the weather history, so that it could include decisions as to whether a particular day is a spraying day and a model could be constructed for a whole spraying season.

These examples have shown clearly the relatively limited benefit of going faster when applying the conventional 220 l./ha rates, the much greater benefit at low application rates, the need to match boom length and sprayer tank size and to make proper provision of water supplies in the field.

Acknowledgements

Data for use in the model has been derived from field observations made by D.C. Lawrence and J.M. Gibbon.

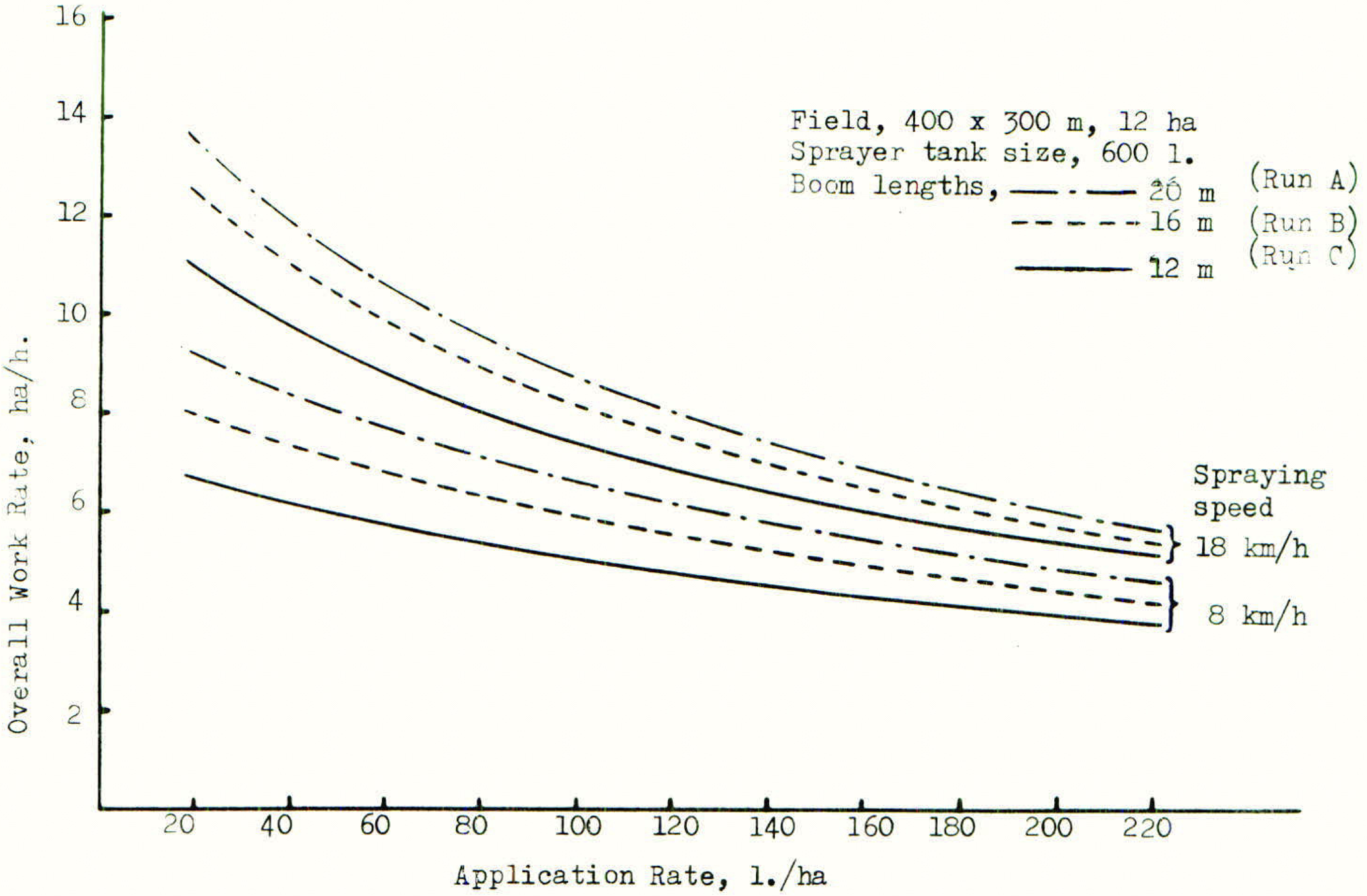

Field, 400 x 300 m, 12 ha
Sprayer tank size, 600 l.
Boom lengths,
20 m (Run A)
16 m (Run B)
12 m (Run C)
Spraying speed
18 km/h
8 km/h
Overall Work Rate, ha/h.
Application Rate, l./ha
16
14
12
10
8
6
4
2
20
40
60
80
100
120
140
160
180
200
220

Fig. I.

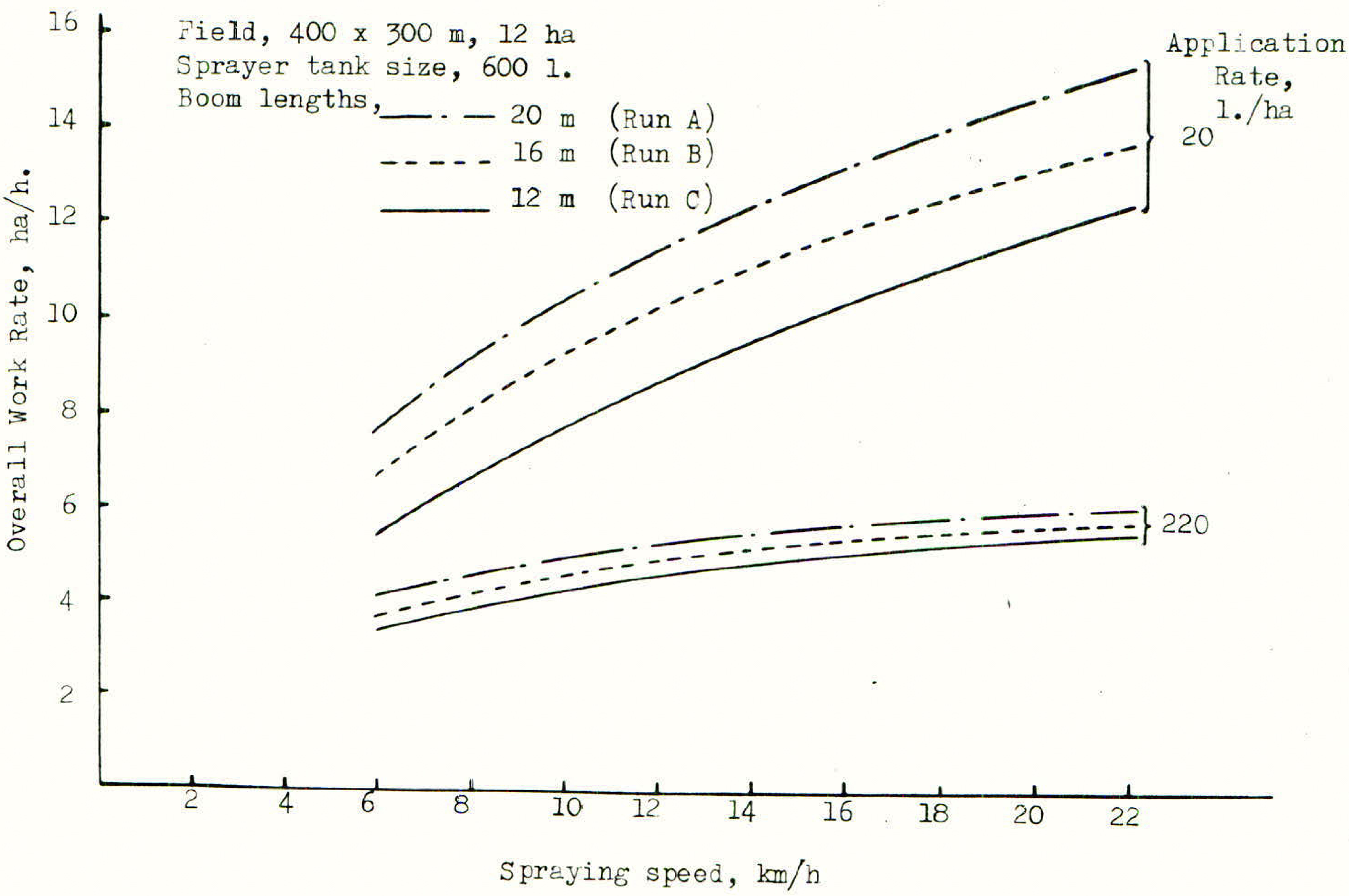

Field, 400 x 300 m, 12 ha
Sprayer tank size, 600 l.
Boom lengths,
20 m (Run A)
16 m (Run B)
12 m (Run C)
Application Rate, l./ha
20
220
Overall Work Rate, ha/h.
Spraying speed, km/h
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
20
22

Fig. II

Proceedings 1978 British Crop Protection Conference - Weeds

DEVELOPMENTS IN SPRAYER BOOM DESIGN

H.J. Nation

National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford. MK45 4HS

Summary After a brief account of early N.I.A.E. work on the dynamic behaviour of sprayer booms in the field and on a standard bumpy test track and of the conclusions made, the more recent commercial developments in boom design and mounting methods are reviewed.

Comments are made on how closely these appear to agree with those aspects which the early experiments showed to be desirable. The several advantages of more stable booms are discussed. The possible effects on boom design of trends in application methods are briefly considered.

INTRODUCTION

Studies in the Spraying Department of the N.I.A.E. on dynamic boom behaviour in the field followed a survey of farm spraying practice when very large variations in the distribution of spray on the ground were measured. Various possible reasons for the deposit variations were studied and it was finally decided that the major contributor was the errant movement of the spray boom. A technique was then developed by means of which measurements could be made of the vertical and horizontal movements of spray booms in the field. The technique was used, first, to measure the movements of booms on 14 different farm sprayers in practical spraying conditions and, later, to measure boom movement over the standard bumpy test track at the N.I.A.E.

The measurements with the farm sprayers showed that although boom tip movement reflects, to some extent, details of boom design the major factor is the method which the boom is mounted on the sprayer. For minimum movement of the boom the mounting method should afford flexibility to isolate the boom as much as possible from the rapid yawing and rolling motion of the sprayer frame. Although this early work was prompted by the desire to reduce the variation in the deposit, more recent interest has been in the use of longer booms and in higher spraying speeds and these factors are probably more responsible for the considerable recent commercial developments. Among the conclusions of the early N.I.A.E. experiments was one that the booms should be carried in a cantilever manner on the sprayer and should be as stiff as possible.

In the commercial developments this appears to have received minor attention in comparison with methods of mounting the boom structure on the sprayer frame by means that will reduce transmission to it of the rolling motion of the sprayer. The following sections comment briefly upon support methods, - first, those with some form of vertical springing, second, those where the boom hangs as a simple pendulum, third, those in which the boom is suspended on a linkage and fourth, those developed at N.I.A.E. where the provision of axes of rotation are specific objectives of the design.

SPRING SUPPORT

In one of the earliest methods the boom was contrained to rise and fall on vertical slides on the rear of the sprayer frame, the weight of the boom being supported by a spring. Frictional or viscous damping may or may not be provided in an attempt to reduce the oscillations which might otherwise occur. Such a system may reduce the transmission to the boom of the highest shock loads but, in general, the provision of the vertical slides does not isolate the boom from the rolling and yawing motion of the sprayer. The N.I.A.E. work has shown that the majority of the motion of a boom tip, vertical and horizontal, arises purely through the rolling and yawing motions of the sprayer. The objective would be met to some extent by those proposals in which the vertical slides are themselves mounted flexibly on the back of the sprayer frame and are capable of tilting and moving one from the other to some extent, though it is not known that these have been applied in practice.

SIMPLE PENDULUM

Around the time of the early N.I.A.E. experiments on boom suspension, there was discussion in the technical press of the possibility of hanging a boom as a simple pendulum on the back of the sprayer, or even of hanging the whole sprayer as a pendulum on the tractor. The simple pendulum suspension was the first type examined by the N.I.A.E. on the standard bumpy test track. A conventional sprayer was used for these experiments; it was equipped with a 9 m boom. This was carried on an A-frame attached to the central portion and this was itself supported from a pivot on another A-frame attached to the sprayer frame. The pivot was about 0.8 m above the centre of gravity of the boom. Provision was made for clamping the boom solidly to the sprayer or allowing it to swing freely as a pendulum with viscous damping to restrict the swinging of the boom, Fig. 1.

Experiments showed that boom tip movement was reduced very little by hanging the boom as a simple pendulum. Watching the rig in action on the bumpy test track it was not difficult to understand why this should be. The effect of the rolling motion of the sprayer was to oscillate the suspension point rapidly from side to side. The boom was of conventional tapered formation and, therefore, with its mass concentrated below the pivot point, rapid oscillations side-ways of the pivot point caused the boom more to rotate about its centre of mass than to translate laterally.

Recently there has been considerable commercial use of the simple pendulum suspension, but in the majority of cases it has been associated with long booms. With these where the rotational inertia of the boom about its centre of gravity is much higher in relation to its weight than is the case with the small boom, this method of suspension is more successful. Whilst the mass of the boom increases proportionally with the length of the boom, the polar inertia goes up as the square of the length. Perhaps, also, since large booms are more usually associated with heavy trailed sprayers, the side-ways oscillation of the pivot point is rather less rapid than with a light, tractor-mounted sprayer.

However, there is one fundamental disadvantage with simple pendulum suspension of a boom and that is when spraying across a side slope. Naturally, the requirement is that the boom should remain parallel to the surface of the ground rather than horizontal. Therefore, means have had to be found to tilt the boom the appropriate extent one way or the other to bring it parallel to the ground surface. Various methods to achieve this have been proposed or used. In one case, the suspension point on the boom is carried on a rocking lever which may be displaced to one side or the other by means of a hydraulic cylinder also fastened to the boom. With the pivot point displaced to one side the boom, in bringing its centre of gravity vertically underneath the pivot, adopts a sloping position, Fig. 2.

Another method depends on displacing the effective centre of gravity of the boom to one side or the other of centre of the boom, in order that the boom shall again adopt a sloping position under its point of suspension. This may be done by a supplementary heavy weight, hanging from the same pivot, which can be forced to one side or the other by means of a hydraulic cylinder fastened to a boom structure. Another method is by having a pair of weights, one on each side of the boom, attached to cables and pulleys in such a way that the weights can be drawn to the left or to the right to off-set the centre of gravity. A similar result can be achieved by having two small tanks on the boom and means to displace liquid from one tank to the other to achieve the required amount of off-set.

These methods inevitably have the disadvantage that at each end of the side-sloping field the operator has to reverse the correction process, either by the hydraulic ram which displaces the pivot or the bob weight or the sliding weight or by displacing liquid from one tank to another, and he has to adjust these to the required extent each time. Automatic methods of carrying out this adjustment could be incorporated, Fig. 3.

With large booms the need to carry additional mass which can be shifted from one side to the other would be a distinct disadvantage and usually these are arranged such that on a side-slope the centre section only of the boom remains horizontal and the extended portions to each side are appropriately raised on one side and lowered on the other by hydraulic rams so that they are parallel to the ground surface; however, the responsibility remains with the operator to carry out these two adjustments at each turn.

TWIN-LINK SYSTEMS

There appear to be two basic types of twin-link suspension for sprayer booms. In one, called for convenience 'A' formation, the links disposed symmetrically to either side of the centre of the boom are inclined inwards so that if projected upwards they meet at a point as little as $\frac{1}{2}$ m or as much as 2 m, possibly, above the centre of the boom. Twin-link suspensions appear to have been in use for about 4 years, Fig. 4.

One of the first applications, in about 1973, was on the Belgian Allaeys sprayer which employed a system patented by Francis de Meeus. Systems employing the 'A' formation of the links have a disadvantage similar to that of the simple pendulum. On a side slope the boom adopts a position intermediate between horizontal and the line parallel to the ground surface. Thus, for cross slope working, either some form of compensation as already described has to be employed or a locking device is provided to put the twin-link system out of action and render the boom rigid with the sprayer.

In the other arrangement, called for convenience 'V' formation, the links slope inwards, downwards and if continued would meet at or near the centre of gravity of the boom. Arrangements having links in 'V' formation have the advantage that usually the boom is very strongly urged towards a position parallel to the ground surface. As the boom is disturbed from this position the motion of the centre of gravity is in the form of a sharply pointed cusp and a very strong restoring force exists for returning the boom to its rest position, Fig. 5. This system has been used for 2 years by one United Kingdom manufacturer.

An interesting feature in the sprayers constructed by Allaeys to the design of de Meeus was that there was a vertical pivot. This is in line with the findings in the N.I.A.E. experiments as it provides some means of isolating the boom from the yawing motion of the sprayer, but it is not in current production.

More recently introduced by Allaeys is a system patented by Pierre Demaret. In this, one pair of inclined links supports a dummy beam from which the boom is itself suspended through another pair of inclined links, Fig. 6. There is provision for using both pairs of inclined links in either 'A' or 'V' formation. It is recommended that 'A' formation should be used on level ground and 'V' formation should be used when spraying across hill sides. The conclusion may be drawn that the 'A' formation is more effective in isolating the boom from the rolling motion of the sprayer, but 'V' formation must be used on hill sides although possibly less effective for isolation. This system does not isolate the boom from the yawing motion of the sprayer since the boom is constrained to swing within slides.

N.I.A.E. DEVELOPMENTS

In the N.I.A.E. experiments on different methods of mounting booms on sprayers carried out in 1972 the final development was of a form of mounting incorporating both horizontal and vertical pivots. The horizontal pivot provided isolation from rolling motion of the sprayer and the vertical pivot isolation from yawing motion of the sprayer. In each plane the boom was restrained, in the long term, parallel to the tractor axle by pairs of springs and it was prevented from oscillating by viscous dampers, Fig. 7. This gimbal mounting, as one may call it, was successful in reducing boom tip movement by more than 50% in the vertical plane and by more than 60% in the horizontal plane, Fig. 8. As yet there appears to have been no commercial development of an arrangement giving similar effect.

Recently a proposal has been made of, and a patent applied for, a system based on a twin-link suspension whereby there are universal joints at both ends of each link so that in addition to providing the flexibility in the rolling mode it is also possible for the boom to be isolated from the yawing motion through its suspension on this pair of links, Fig. 9. It is necessary then to restrain the centre of the boom roughly in its correct position by means of links, or rollers with slides. The novelty of this system lies in the use of one pair of links to provide the isolation in both planes. Also, the restoring force is provided entirely by gravity and springs are not necessary.

In line with the other part of the N.I.A.E. recommendation, a boom supported by either of these systems should be a cantilever and stiff in both planes. Also, because it is isolated by suspension from the more rapid sprayer movements, the boom does not have to be such a strong structure as it would have to be if attached rigidly to the sprayer and able to withstand high shock loads.

Thus a boom can be of virtually parallel cross-section throughout its whole length in both the vertical and horizontal planes which gives it the high polar moment of inertia which aids stability without being of exceptional weight.

OTHER ADVANTAGES OF BOOM STABILITY

With a stable boom properly equipped with good spray nozzles one can expect a more uniform distribution of spray, but other advantages accrue. Since there is less fear of the boom striking the ground it is possible to adopt a lower notional boom height. This has the advantage of reducing the potential for drift of spray away from the boom and of achieving better penetration of the spray through the canopy and placement at the target area. Naturally it is necessary if using standard angle spray nozzles to have them at a closer spacing and for this purpose one-third of a metre is recommended or, alternatively, with the greater spacings of either 18 in. or half a meter then nozzles of a wider angle should be used. Alternatively, the standard nozzles can possibly be inclined to spray either forwards or backwards to achieve the necessary overlap of spray pattern. Other advantages will be that the use of swath matching aids will be assisted by the provision of a more stable mounting for the equipment, and longer booms or higher spraying speeds are feasible.

Whilst greater stability of the boom will permit the use of longer booms there must inevitably come a time when the boom length is such that the ground surface over which the sprayer or tractor wheels are passing is no longer representative of the ground surface level far out to either side of the machine. If long booms are required in these circumstances possibly articulation of the boom is a solution.

NEW DEVELOPMENTS IN TECHNIQUES

The use of more stable booms may be an integral part of the successful adoption of new application techniques such as low volumes and CDA. In the case of CDA, the spray drops fall under gravity and the shorter distance they have to fall the better the chance that the proper over-lap and correct distribution will be achieved. With low volumes where the spray spectrum may be somewhat finer there is a need to reduce as much as possible the chance of the spray being subjected to the effect of wind. Thus in both cases it may be necessary for the booms to be closer to the crop or target area.

CONCLUSION

In this short paper an attempt has been made to review some of the considerations which must be borne in mind in sprayer boom design and to comment on some of the most interesting recent developments in boom design and boom mounting. It is hoped that the point has been made that this is a most important area of design.

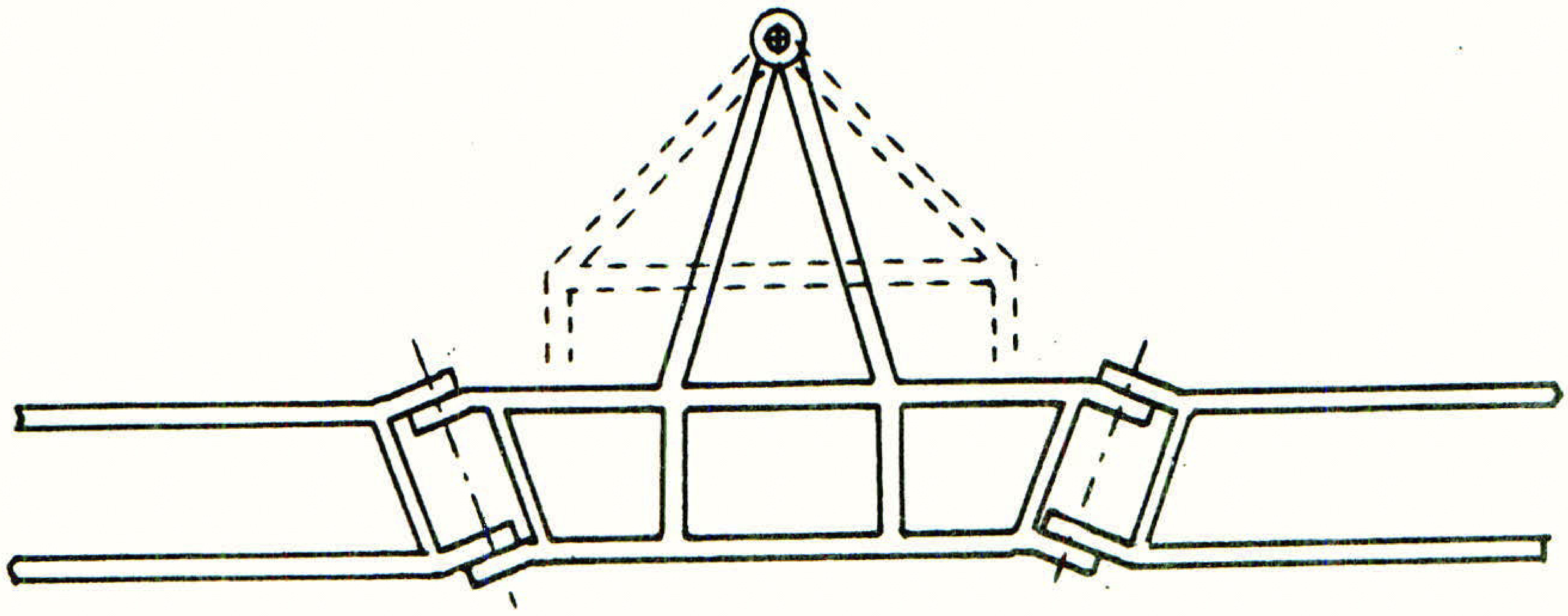


Fig. 1 Simple pendulum mounting

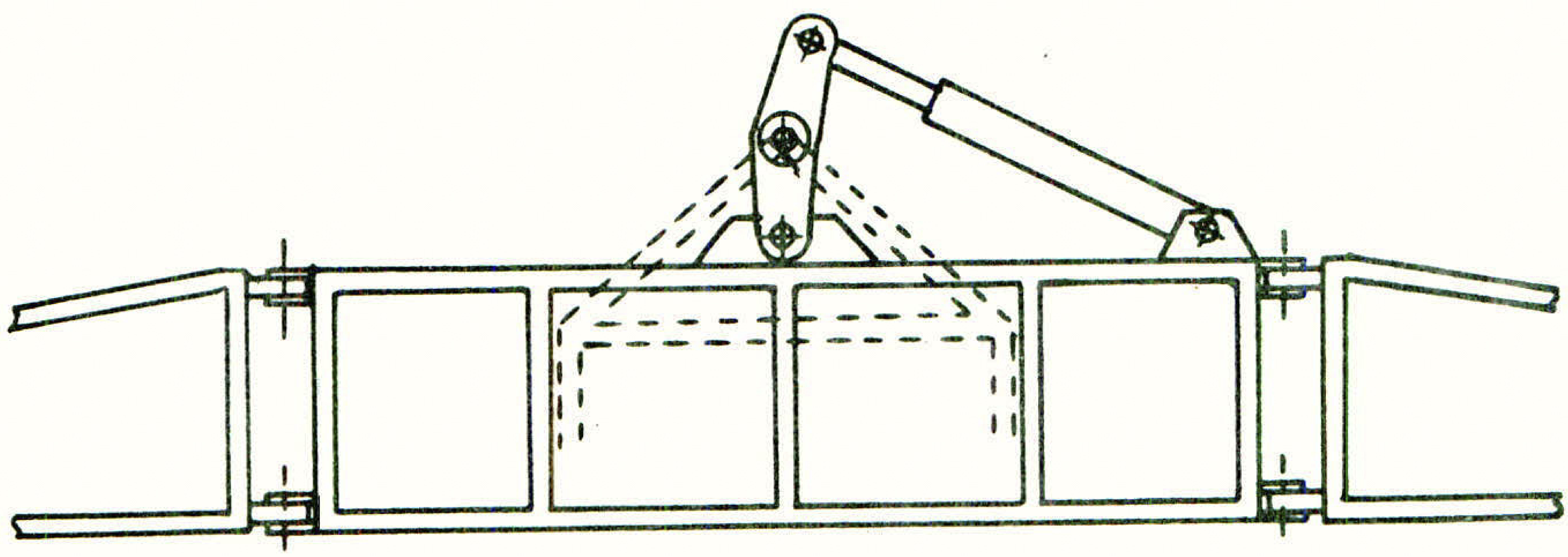


Fig. 2 Pendulum with swinging link to offset pivot on boom

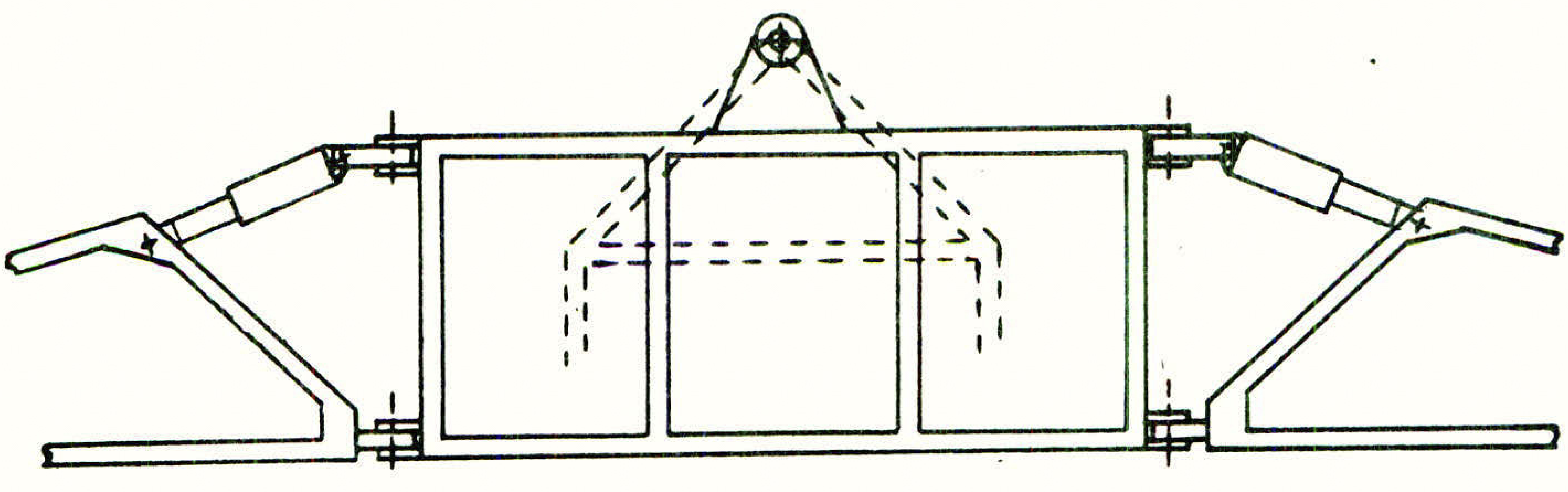


Fig. 3 Pendulum with independant control of side sections

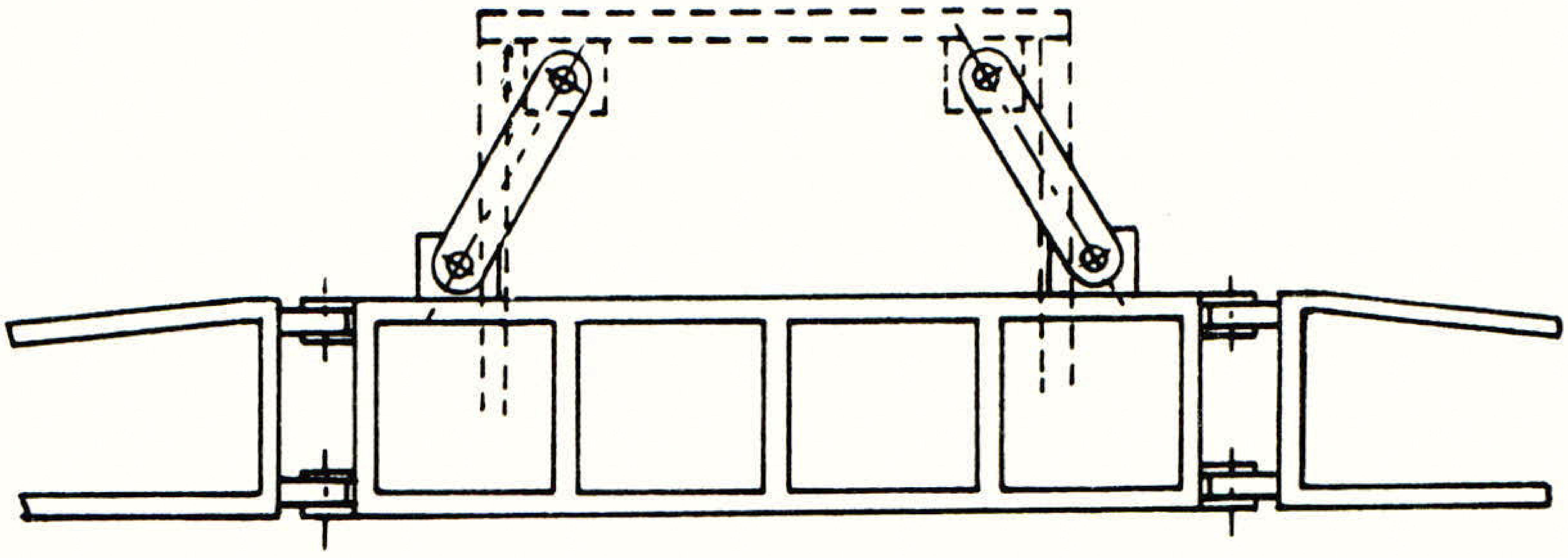


Fig. 4 Twin links in A-formation

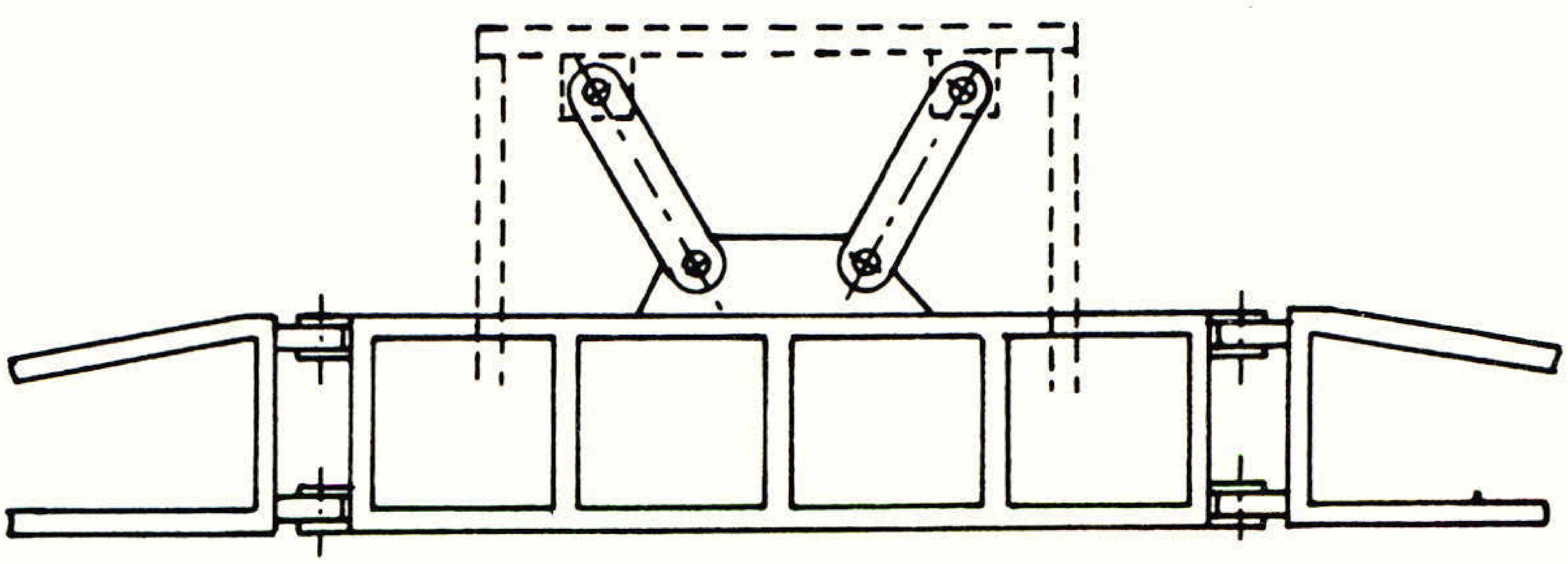


Fig. 5 Twin links in V-formation

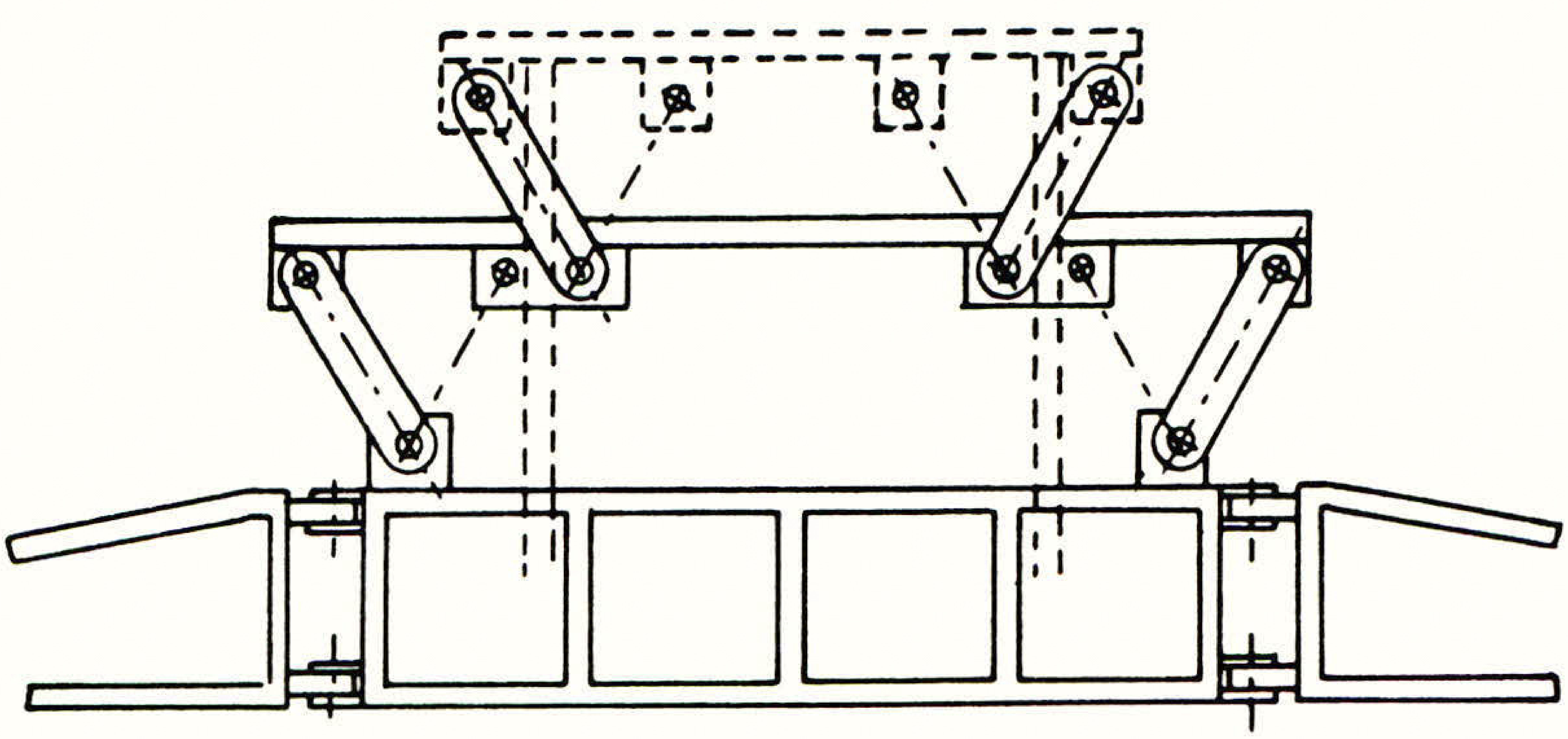


Fig. 6 Demaret-type four-link suspension

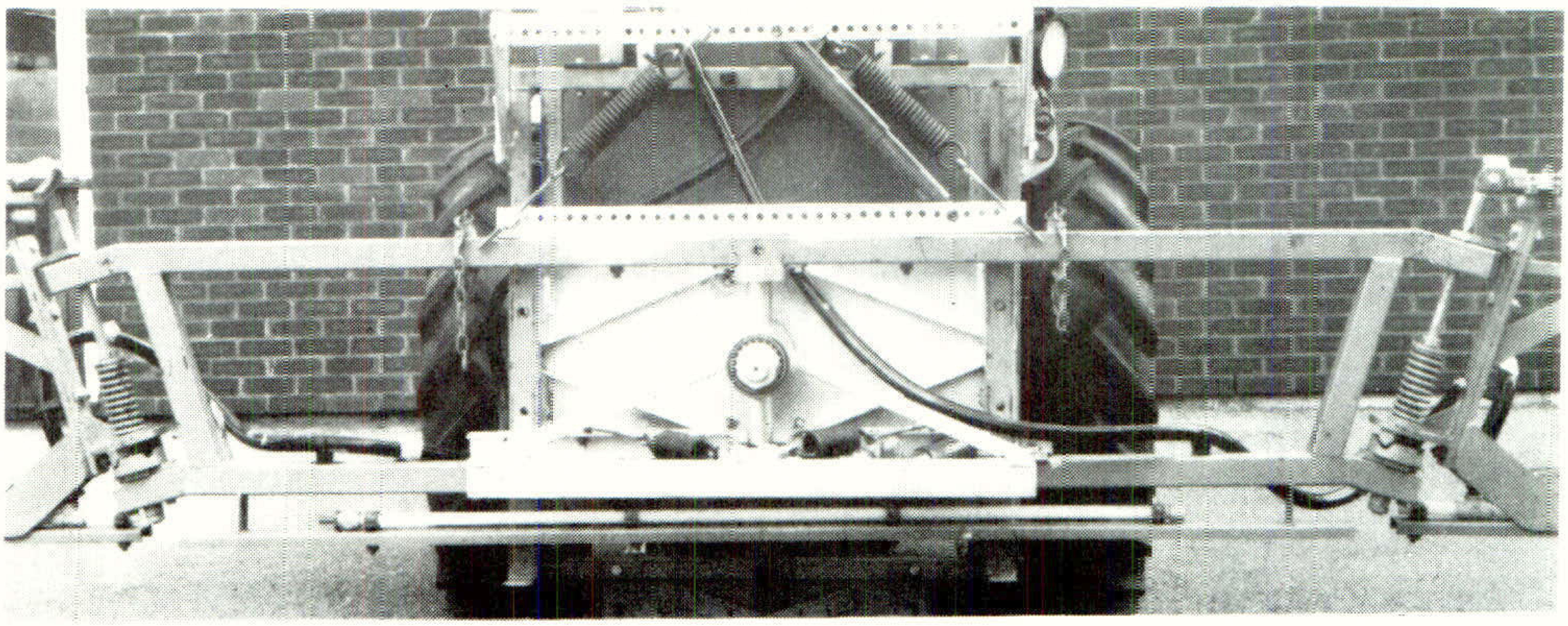


Fig. 7 Gimbal-mounted boom

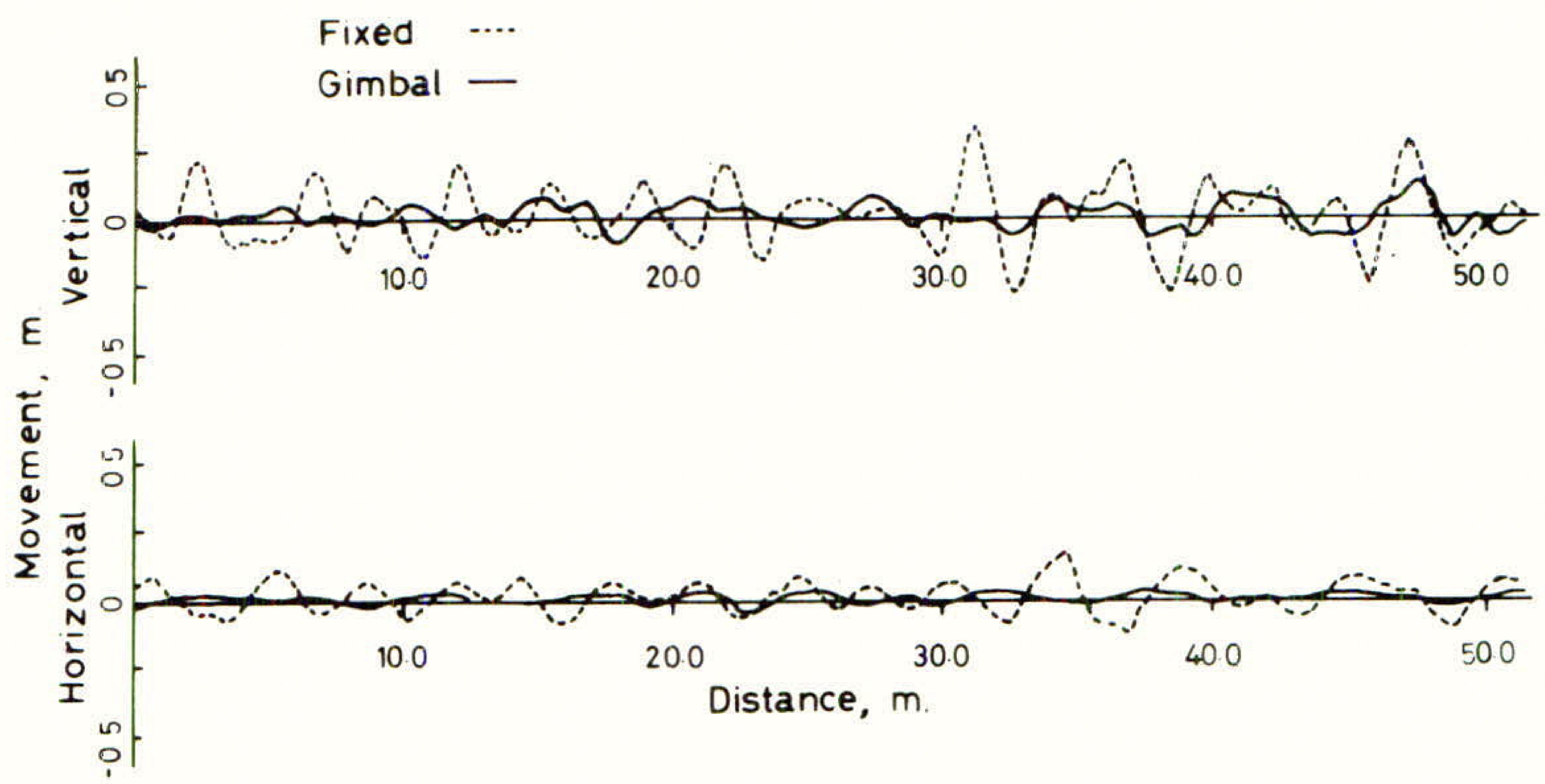


Fig. 8 Improved performance with gimbal mounting

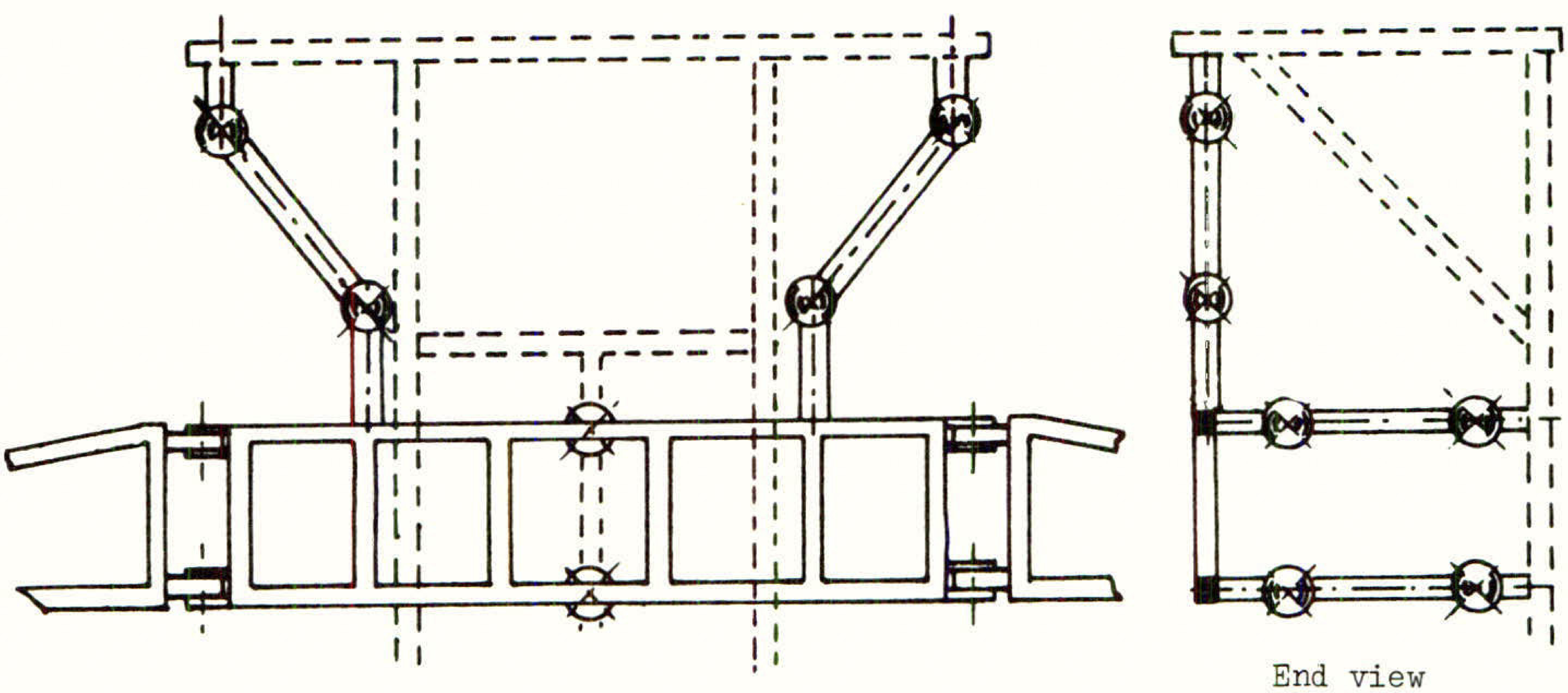


Fig. 9 Universal twin-link mounting

Proceedings 1978 British Crop Protection Conference - Weeds

NEW DEVELOPMENTS IN SWATH MATCHING

D.C. Lawrence

National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford. MK45 4HS

Summary A new development of swath matching aids is discussed, that of the closed circuit television system. Also a new method of measuring the accuracy of spraying in the field by using aerial photographs is explained.

INTRODUCTION

In recent years there have been several developments aimed at improving the accuracy of spraying, particularly so in the aids designed to assist in matching the adjacent bout or swaths of the crop sprayer as it progresses across the field. Since the initial request to the NIAE by the British Crop Protection Council in the early 70's to investigate swath matching aids, the Institute has looked at many commercial instruments mostly in the navigational field which with suitable modifications might have been suitable for this purpose, also the Institute has continued to monitor any developments in swath matching systems as well. A review of these investigations in to swath matching aids was the subject of a paper given at a Subject Day on Spraying held at the NIAE in October 1977. (Lawrence, 1977). At that time reference was made to the possible future use of close-circuit television as a means of swath matching.

METHOD

This method has, in fact, now 'arrived', the unit is manufactured by Pye Business Communications of Cambridge and consists of two cameras and a monitor; the cameras are contained in two specially made housings which protect the cameras from spray and dust. These housings are fitted one to each end of the sprayer boom and look ahead in the direction of travel at a line of foam blobs which have been laid down on the previous bout of the sprayer, and this picture is transmitted to a monitor fitted in the tractor-cab sighted in front of the driver; also fitted in the tractor-cab is a control to select which of the two cameras is in use. The advantage of this system is that the foam blobs are viewed as if by the human eye, so that if the line of blobs tends to be a little scattered, one can average off and compensate for this variability. Another feature of the television system is it's adaptibility, the system may be used for other purposes as well, for example, observation of a particular section of a grain-handling or drying plant; it can be used for security purposes and it has already been used for observation of lambing pens and there is undoubtedly many other uses to which it can be put.

At the present time the farmer has a wide choice of swath matching aids and these methods include tramlining and the alternative ways of producing these. All these different methods provide a highly controversial topic amongst farmers and in order to evaluate the efficiency and accuracy of these various swath matching systems, Spraying Department of the NIAE, have evolved with the co-operation of ADAS Aerial Photographic Unit based at Cambridge a method of using aerial photography to measure the accuracy of spraying in the field. In past years these measurements had to be carried out by hand, were painfully laborious and slow, and at the most only some forty actual measurements were made per field. With the present method at least 100 measurements may be carried out per field; if the field is a large one this number may be increased two or three times, consequently, the measure of accuracy is very much greater.

The method of operation used in aerial photography is as follows. On the selection of a particular field for investigation, two markers are placed ideally on the field headland 100 m apart, at right angles to the direction in which the spraying has taken place. The aircraft flies over the field initially at 3,000 ft to provide a general view of the field and it's relation to the surrounding fields. A further flight some 1,300 ft above the field is then made and a series of photographs taken, both using panchromatic and infra-red film. The number of photographs taken being dependant on the size of the field.

At the present time, due to the effects of aberration it has been found necessary to largely discard at least 1 in. round the edge of the photograph for measurement analysis, but in order to qualify this error it is intended in the very near future to place markers at set distances across the field to completely fill the frame of the photograph, then to photograph from the air and having then established the inherent error, be able to use the whole area of the photographic print. At the present time the tractor and sprayer wheelmarks on the photograph are highlighted by hand before passing through the chart reader at Rothamsted for analysis, the results are then processed through the computer and are presented as measurements of swath accuracy in terms of the number of times the sprayer has under or over-lapped and the percentage of matching errors are also provided.

DISCUSSION

An initial trial of aerial photographic measurements of swath matching accuracy was carried out last year and although there were a few minor difficulties the results were promising and illuminating. Consequently, this year a much more comprehensive programme was prepared; already a few different swath matching methods have been photographed during the initial spraying season and although it is too early as yet to provide any actual results from these photographs, it is intended to carry out more aerial surveys during this Autumn which should reveal some of the problems in matching swaths particularly when applying pre-emergence sprays. It is then the intention to publish the results of these findings this Winter and the results should provide data on the accuracy of the various swath matching methods which are practiced today.

References

LAWRENCE, D.C. A review of swath matching methods. Paper pres. NIAE Subject Day "Spraying on Large Cereal Farms", Oct. 1977.