Roadside Cover Equipment

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• THE WORK summarized here was initiated in 1958 at the Agricultural Engineering Department, University of Illinois, by the late George E. Pickard and covers several years of project activity. The main justifications for the project were the rapid increase of roadside acreages expected from the construction of the Interstate Highway System and the frequent failures of the equipment, techniques, and flora borrowed directly from agriculture to properly establish and maintain roadside cover. These failures were not too surprising because the conditions along roadside rights-of-way were radically different from those found in agricultural production. The cover was often grown on slopes seldom encountered in farm fields or even pasture land, and most of these slopes consisted of raw subsoil. The so-called superhighways had also produced deeper cuts and longer, sometimes steeper, slopes than those encountered in most of the past construction, and the problems of establishing cover had become more severe. Eighteen to 25 acres of grass per mile of Interstate highway plus an average of 40 acres per interchange helped to justify this project in which the effort was not only to find modest improvements but also to approach the problem as one where new cover species, new techniques, and new machines might be required.

The objective in the study was to develop and evaluate ideas and to formulate design principles and information that would lead to the production of equipment for more effective and economical roadside development and maintenance. A further and more immediate objective was to improve existing machines and develop more effective techniques for their use.

Studies of individual machinery problems were undertaken as the urgency of need appeared to dictate and as indicated by a national survey conducted by the project and previously reported (1). This survey of all state highway agencies and toll road authorities provided information on the types of equipment used for the establishment and maintenance of highway right-of-way and an assessment of their performance, convenience, and overall cost of operation. A project advisory committee was also quite helpful in selecting those areas needing investigation and in providing technical guidance.

The project involved several areas of activity that can only be summarized at this time. Detailed findings of the various phases of the project have been reported in several individual reports and publications, most of which are cited in the References.

TILLAGE, SEEDING, AND FERTILIZING

A survey indicated that about one-fifth of all new highway roadside seedings required reseeding at least once before cover was firmly established (1). In addition, the shoulders and ditches of older roadsides in agricultural areas where fall plowing is practiced require occasional reshaping to their original profile because of soil buildup in the roadside cover. Reshaping leaves large areas of bare shoulder and ditch that also must be reseeded. It was in the small area or "spot" reseeding and the reseeding of reshaped shoulders and ditches that an attempt was made to improve the equipment and practices used.

Work in Illinois and contacts with research personnel in other states indicated that small area reseeding was often a largely manual operation, costly in both labor and

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materials. If the operation was mechanized, a tractor was needed with a leveling blade, a disk harrow or other tillage tool, a fertilizer applicator, and a seeder. If only one tractor was available, rains occurring before the operations were completed often made it necessary to start over. If rain did not occur, the soil often was too dry by the time the seeding was made.

Exposed subsoil found on Illinois highway roadsides is nearly always extremely low in available nitrogen and phosphorus (2). Research has shown that the best response to fertilizer applied at seeding time is obtained when the fertilizer, especially phosphorus, is placed in the root zone and not in contact with the seed. After considering the conditions, project personnel concluded that a tractor-mounted implement was needed that would till the soil in 1 or 2 passes, apply fertilizer in the soil, drop the seed at a shallower depth than the fertilizer, and then firm the seedbed.

Three commercial machines were then obtained and used in seeding establishment trials during several seasons (3). The first machine obtained and evaluated was the Pasture Dream, produced by Taylor Machine Works (Fig. 1). This machine penetrated the soil with a set of rolling coulters, followed by fertilizer boots with hardened points that could penetrate to a 6-in. depth. Three hoppers permitted applying fertilizer, small grain or bulky seeds, and small-seeded grasses and legumes. Row spacings of 10 and 20 in. were possible.

The other 2 machines were the Deere 265 landscape seeder (Fig. 2) and the Deere MLF-6 fertilizer seeder (Fig. 3). The 265 landscape seeder had been modified at our request with a row of 12 flat spring teeth on a heavy mounting bar in front of the standard light leveling tines to permit tillage. The tillage teeth were later mounted in staggered form on 2 bars for better performance. Row spacings down to 6 in. were easily obtained. The MLF-6 was a heavier machine having larger hoppers, a stronger frame, and a higher center of gravity. Row spacings of less than 10 in. were difficult to obtain with the heavy coil spring teeth used for tillage (Fig. 3).

Many successful seedings were obtained with the units during trials on back slopes, shoulders, ditches, and interchange medians. However, several modifications were found necessary, and none of the machines was entirely satisfactory as available from the manufacturer. It appears that a machine should be designed and produced specifically for roadside use rather than modified from an existing machine.

We believe a satisfactory roadside tilling, seeding, and fertilizing machine would require the following design features. It should be lightweight, under 1,000 lb empty weight if possible, yet rugged enough to withstand severe use. Total hopper capacity should be limited to about 250 lb of fertilizer and 50 lb of seed mixture. A low center of gravity is desirable with an overall unit width of less than 7 ft. Tillage teeth should be 1- by 2-in. flat standard or 1-in. coil spring stock with provisions for a 3- to 4-in.

Figure 1. Relationship of hoppers and other components on Pasture Dream seeder.

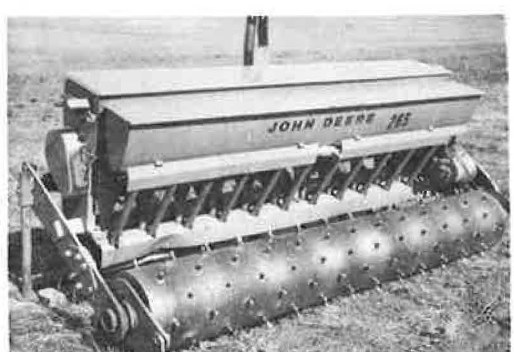

Figure 2. Spiked roller, drag chain, and feed tubes of Deere 265 landscape seeder.

flotation of each tooth. Two staggered rows of teeth should be used with 12-in. spacing in each row to give an overall 6-in. spacing. Fertilizer tubes should place the fertilizer behind the teeth and within 1 to 2 in. of tillage depth. Seed tubes should place the seed about 2 in. behind the fertilizer tube and in the soil about $\frac{1}{4}$ to $\frac{3}{4}$ in.

Provisions should be made for the operator to easily change the mode of machine operation from tillage alone to tillage and seeding or to tillage, fertilizing, and seeding so that varying numbers of passes can be made over the soil to ensure a good seeding under widely varying conditions. A 3-point hitch mounting should be provided, and the unit should be articulated in the center across the swath to permit the teeth to more nearly follow the soil profile. The pivot point should be about one-half the implement height and below the hoppers. Seeding rate capabilities should range from 10 to 150 lb/acre for any grass-legume mixture; fertilizing rates should range from 100 to 1,000 lb/acre. Soil should be firmed with a packer wheel behind each seeded row.

Figure 3. Deere MLF-6 fertilizer seeder as modified for first seeding trials.

Much more detailed information on the seeders, their use, and resulting recommendations is available in the report published on this phase of the project (3).

Another activity involved an analysis of particle trajectories and their application to a broadcast distributor that would spread a uniform application of seeds or granular fertilizers. The forces acting on a sphere moving through an undisturbed medium under the influence of gravity and the drag of the medium were characterized by a set of differential equations. Simulation with the aid of a general purpose, electronic, analog computer showed trajectories and variations in velocity and drag coefficient for several plastic spheres, seeds, and granular fertilizers. The drag coefficient varied considerably where the Reynolds number was low, and remained essentially constant at higher Reynolds numbers. Experimental verification of the analog solutions (Fig. 4) showed most actual trajectories within 10 percent of the theoretical solutions (4, 5).

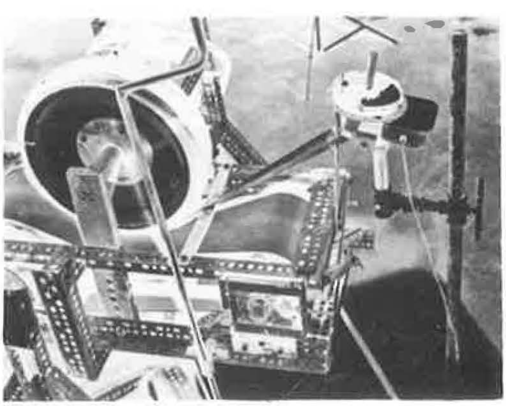
Figure 4. Apparatus used to throw individual particles to verify trajectory equations.

ROADSIDE MULCHING

Mulching with straw or other materials has become a standard practice when permanent seedings are established. A national survey indicated that most users felt the mulch blowers perform fairly well but some wanted a longer throw, a better feeding mechanism, and a mulch of individual strands rather than either bunches or short pieces. After field observations and user contacts, project engineers decided that a more even feeding of the baled material into the machine would provide less bunching of the applied mulch. The logical solution was to replace the manual feeding of bales into the mulcher with a mechanical feeding table. In addition to providing a more uniform mulch, this would eliminate one man from the op-

Figure 5. First version of mechanical feed table for delivering baled straw to mulcher.

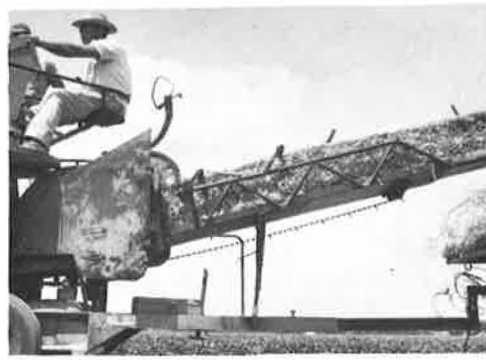

Figure 6. Second version of mechanized feed table with smaller bearings, longer feed chain teeth, and welded side rails.

eration, and the machine capacity should be increased because of more continuous feeding.

A commercial mulcher was obtained and adapted to mechanical feeding (6). Care was taken to make as few changes as possible in the rest of the machine to keep the adaptation simple and inexpensive (Fig. 5). The unit was used with some success during one season and then was modified considerably for the next season (Fig. 6). One of the most useful modifications was the addition of a solenoid control so the blower operator could stop and start the feeding to prevent overloads or to skip lanes and ditches.

This unit was so successful in meeting the design objective that Amalco, Inc., an Illinois landscape seeding contracting company, made up three more like it for its use. The feed table was accepted very rapidly by other landscaping contractors after the Finn Equipment Company introduced its version in 1965 (Fig. 7). At the present time, nearly all their large mulchers are sold with the mechanical feeding table.

To provide labor and time savings when unbaled mulches such as corncobs are applied to shrub beds and ground covers, an attachment for processing and conveying corncobs was developed (6). A large hopper and elevator (Fig. 8) were used to move cobs from dump trucks to crushing rolls (Fig. 9) that quartered the cobs before they passed into the mulch blower (Fig. 10). Additional versatility was later provided by simplifying the corncob processor so that other unbaled mulch materials such as sawdust, wood chips, and leaf litter could be handled (Fig. 11). In the later version the crushing rolls were removed and the flail chains in the mulcher were relied on to process the corncobs.

Figure 7. Production version of mechanical feed table.

Figure 8. Finn straw mulcher with modifications for applying corncob mulch.

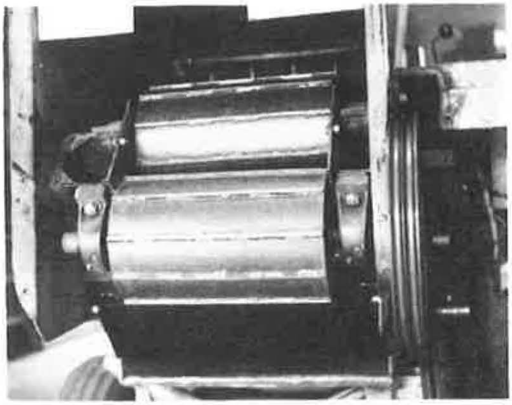

Figure 9. Crushing rolls mounted in throat of straw mulcher.

Figure 10. Shrub bed mulched with corncobs processed through modified mulcher.

MOWING OF ROADSIDE COVER

Sicklebar, horizontal rotary, and flail knife mowers are the most common machines used for cutting roadside grasses. The presence of rocks, rubbish, and debris is a hazard to all these mowers. The sicklebar mower will dull, chip, or break if it strikes obstacles. The horizontal rotary mower often throws objects, and these endanger operators, motor vehicles, and motorists. The flail knife mower has a high power requirement and excessive maintenance costs. Project activities in the area of mowing were primarily concentrated on the horizontal rotary mower (7, 8, 9) and the flail mower (10).

Research on horizontal rotary mowers began with observations of the movement of material through a specially prepared Ford rotary mower. The mower had been modified by placing transparent plastic plates in the top of the case through which the material movement could be studied by high-speed photographic techniques. Later, some of the plates were removed, and the effects of their removal on performance were evaluated. Preliminary studies indicated that a large amount of recutting occurred before the material was ejected from the mower and that this cutting action required a considerable amount of power. Observations also disclosed that windrowing was enhanced by material that was cut at the right side of the mower and moved to the left side between the knife tip and the case. Although observations were made with blades of different lift angles, the effect of these angles on the particle movement was not apparent.

Figure 11. Mulcher with revised hopper and elevator for unbaled mulches.

A mathematical description of particle movement on the blade was then undertaken, and equations of motion were derived for the forces and accelerations on a grass particle in a cylindrical coordinate system (7, 8). The analysis resulted in second-order, nonlinear, differential equations that were solved by Runge Kutta techniques with the aid of a digital computer. In an effort to verify the mathematical analysis, we developed a procedure for testing blades in the field by using high-speed photography to analyze particle trajectories from an open rotary mower

(Fig. 12). The results of this study indicated good correlation between the theoretical analysis and actual measurements of material movement in a horizontal rotary mower. It is apparent the blade lift angle is the most important single parameter influencing particle trajectory. Forward speed of the mower and initial particle position on the blade have little effect on particle path or exit velocity of the material. The average coefficient of friction of the material influences particle trajectory significantly, although to a lesser extent than the lift angle. Hence, for a mower with a given blade lift angle, material movement can be specified to some degree.

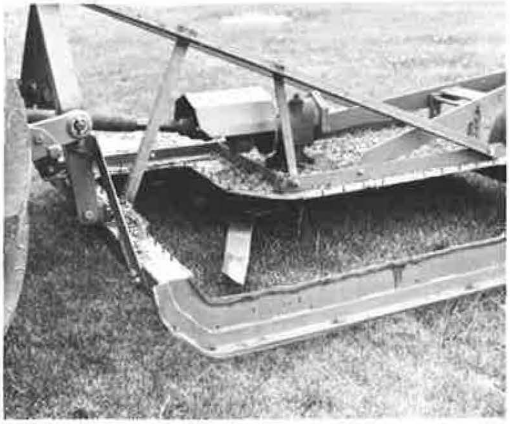

Figure 12. Horizontal rotary mower modified for verification of analytical solution of particle trajectories.

The next challenge was to apply the theoretical analysis to the design of a mower case utilizing the material movement to minimize power requirements, control the direction of flying objects, and eliminate most of the unwanted windrow. Two approaches were made to this problem (9): One involved the addition of an auger to the rear of the rotary mower discharge, and the other consisted of a shelf around the circumference of the blade with a paddle operating at one-quarter rotor speed to move the material and discharge it at the rear of the mower (Fig. 13). The first approach was abandoned after problems were encountered in transferring the material from the rotary blade to the auger assembly. A comparison was made between the shelf discharge mower and a conventional rotary mower in material that had an average height of about 10 in. There was a significant difference in the power requirements of the 2 mowers, with the shelf discharge mower requiring a lesser amount of power. This was primarily due to reduced recutting of the plant during movement in the mower case, a characteristic of the conventional rotary mower. The higher air velocity gusting out the rear of the standard mower was another indication of wasted power. A further comparison was made by using the shelf mower with 2 paddles versus 4 paddles to determine material distribution in the swath. In the case of both alfalfa and orchard grass, there was more even material distribution with 4 paddles.

Figure 13. Shelf discharge mower with part of case removed; paddles move one-quarter the knife speed.

The wide range in flail mower knife sizes and shapes found on equipment in the field prompted project engineers to center the flail mower activity on improved knife design. The approach was to obtain the knife and material parameters needed from laboratory studies of a flail knife cutting a few typical materials and then supply the material characteristics to a computer program that would simulate the dynamic characteristics of a flail knife rotor assembly. In this way, it is possible to develop a flail knife design for a given set of conditions such as grass species used, rotor speed, cover height, and density.

From the analytical study of the dynamic characteristics of the flail knife, it was found that rotor speed and the radius of the rotor are both very influential in the determination of the maximum deviation angle of the flail knife from a radial position during the cutting cycle (Figs. 14 and 15). The height of the crop cut by the flail knife was found to have much less influence on the maximum deviation angle than either the plant density or the energy required to cut one stem. The mass of the flail knife and the mass moment of inertia are proportional for the similar knife geometrics used for the study and have a large effect on the resultant deviation angles of the flail knife. There was close agreement between the theoretical equations derived and solved on the digital computer and the experimental results obtained on the flail knife laboratory test stand (10). Through the use of the digital computer program it was relatively easy to study the effect of the parameters involved on the entire system. The equipment designer should be able to use the equations developed to analyze flail knife design and greatly shorten test time required for an optimum design.

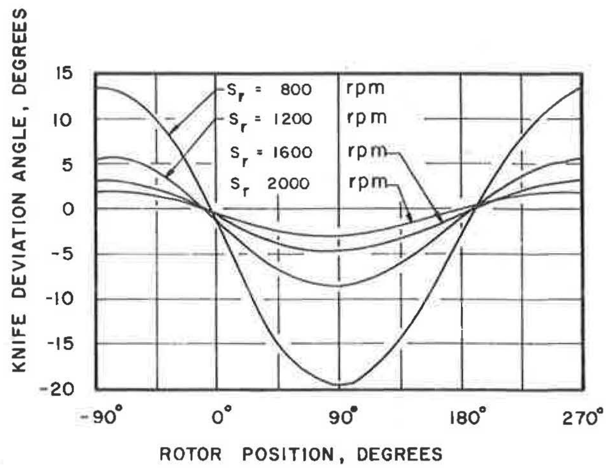

Figure 14. Effect on deviation angle of rotor speed, S_r (rotor position is expressed in deg).

SPRAYING ROADSIDE COVER

During the project activities on spraying, the special requirements of roadside spraying were studied, and modifications of equipment and developments of new components or concepts were then attempted (11). Concurrently, conferences and other contacts with commercial companies were used to encourage improvements in roadside sprayers.

Accurate spray application depends greatly on accurate nozzle output ratings and uniform nozzle spray patterns, so the nozzles were studied first. In addition to the boomless broadcast nozzles, regular flat fan tips and flooding fan tips were studied to compare operating characteristics. Because the boomless broadcast nozzles have the advantage of covering wide swaths, they can be widely spaced thus making it much easier to maneuver around or over obstacles. Nozzle plugging is seldom a problem, because large orifices are used. Besides producing a varied application rate across the pattern, they have the disadvantage of being difficult to overlap properly to get uniform coverage. Also, the swath width varies greatly with travel speed and with wind force and direction.

The regular flat fan and flooding flat fan nozzles have the disadvantage of requiring closer

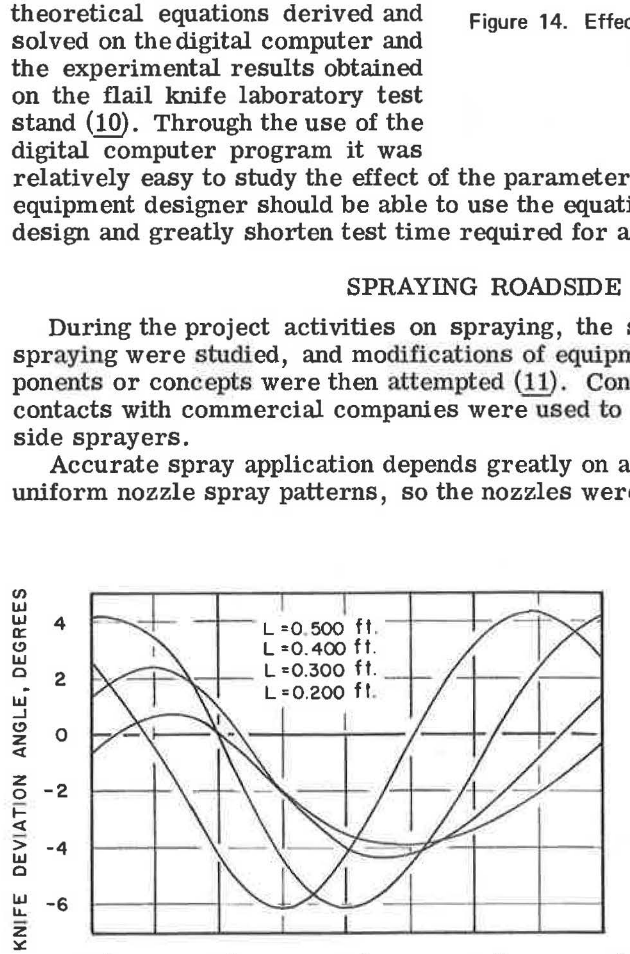

Figure 15. Effect on deviation angle of changes in rotor radius, L (rotor position is expressed in deg).

spacing along the boom. Clearing of signs, shrubs, and mailboxes without causing excess amounts of drift or skips in spray coverage is a major problem. Because the boomless broadcast nozzles seemed best overall, they were studied thoroughly with the hope of improving uniformity of pattern and developing a means of varying the swath width. The 2 most common boomless broadcast nozzles are the off-center nozzle and the radial flow nozzle. Both nozzles produce a pattern of fine droplets under the nozzle and very coarse droplets at the far end of the swath. An experimental radial flow nozzle was designed by project personnel. In tests of the experimental nozzle and 2 commercial nozzles, none had a really rapid drop in rate at the outer end for use at the right-of-way edge, although the experimental radial flow nozzle was best in this respect (Fig. 16).

After the nozzles previously mentioned had been examined and tested, a commercial sprayer was tested and a study was made of custom-operated and state-owned sprayers. Excessive pressure drop was a common fault with all sprayers as well as incorrect mounting of pressure gages, too low boom heights, slow-acting and inconveniently located shutoff valves, and booms that were difficult to pivot and raise.

The problem of nozzle pressure variation is more acute for spraying roadsides than for other types of spraying. The simplest and most economical way to correct this variation in pressure at each nozzle during spraying appeared to be to use an automatic flow regulator for each nozzle. Because commercially available automatic flow regulators were not found satisfactory, a study was made of the various bypass pressure regulators. On the basis of lowest permitted pressure rise, the single-spring, glass-ball, low-pressure regulator was best, and the 2-spring, diaphragm, low-high-pressure regulator was next best. Because it seemed desirable to obtain better control of pressure rise than any of the bypass regulators permitted, other means were investigated. The reduction type of flow regulator appeared to be a desirable alternative, for it not only presented the possibility of limited pressure rise on the nozzle side of the regulator but also eliminated the bypass line and its resulting friction losses. Tests of a ³⁄₄-in. IPT reducing type of regulator showed that it limited the pressure rise much more than the bypass type of valve. A 1-in. IPT reducing type of pressure regulator now used on a commercial highway sprayer limits the pressure rise of the boom during complete nozzle cutoff to 4 psi.

To get satisfactory swath width control, it was assumed that a 20-ft boom with a minimum swath of 20 ft and a maximum of 40 ft would be adequate in most cases. It seemed desirable to have the outer 20 ft of swath infinitely variable. Attempts to develop an infinitely adjustable nozzle were abandoned after several design efforts were

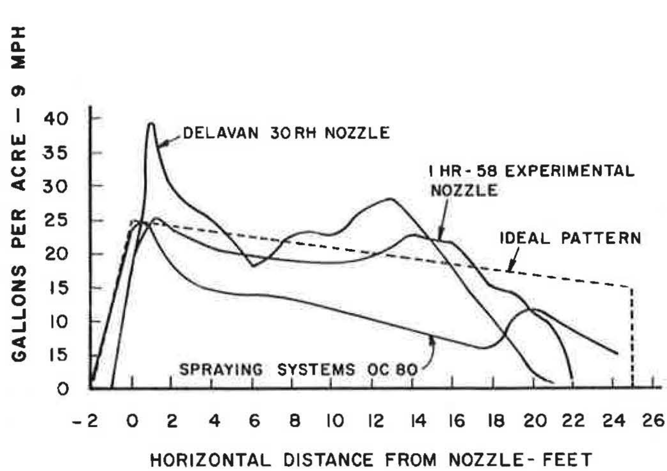

Figure 16. Comparative nozzle patterns at 40 psi, 36-in. spraying height, and maximum swath.

made toward covering and uncovering the orifice of the experimental radial flow nozzle. Nozzle heads were then developed that used a series of orifices to cover the swath in a series of discrete steps (Fig. 17). Figure 18 shows the nozzle head design that was developed and accepted commercially. It uses commercial nozzle tips to cover each segment of the swath and a rotary cutoff valve to control the number of segments and hence the spray width. It has certain advantages in that the control linkage can be a simple pinion and rack operated by push-pull cable; therefore, proper overlaps are easy to obtain by selection of nozzles. Wear on the rotary valve is easily taken up by the spring loading, and wear in the nozzle tips is no problem because they can be replaced without disassembling the nozzle body. On November 19, 1963, U.S. Patent No. 3111268 was issued on the remotely controlled spray head. As a result of this work, Deere and company of Moline, Illinois, became interested in the nozzle head and was licensed to use it on a roadside sprayer they were developing (13).

Figure 17. Rotary valve, adjustable swath, nozzle assembly equipped with rack and pinion, with rack operated by push-pull cable.

VEHICLE STABILITY

The purpose of this investigation was to formulate and analyze a mathematical model that would be suitable for studying and predicting the steady-state behavior of a tractor operating along roadside slopes (13, 14). It was hoped that a method of predicting vehicle behavior might be found so that safety of operations, as well as functional design, could be improved. Various parameter values were used in a computer analysis to study the effects of tractor geometry, including drive and steer design possibilities. Input data for the model were obtained from studies of 3 different tractor and mower units, one of which was equipped with special tires (Figs. 19, 20, and 21). The model was then used to simulate behavior of several hypothetical vehicle designs under typical slope conditions.

With 4-wheel steering, it is possible to eliminate yaw of the vehicle with respect to the desired direction of travel. The yawing of the vehicle, however, does affect the lateral stability and therefore the 4-wheel steered vehicle is somewhat less stable in that regard on steep slopes than is the conventional front-steered vehicle. The

Figure 18. Deere version of adjustable swath, rotary valve, nozzle assembly (all nozzles operating).

Figure 19. Tractor A with side-mounted rotary mower.

Figure 20. Tractor B_1 with rear-mounted rotary mower.

Figure 21. Tractor B_2 with side-mounted sickle-bar mower.

most favorable design for preventing sliding is a 4-wheel drive, and the least favorable of those considered is the front-wheel drive vehicle. On the slopes considered, sliding was the mode of failure always experienced under the steady-state operating conditions.

The dynamic behavior of vehicles operating on slopes was considered in a second phase of the study (15, 16). The tractor and implement were represented as a series of rigid bodies supported on tires having linear spring rates and constant damping coefficients (Fig. 22). The tire characteristics were evaluated independently in the vertical, lateral, and longitudinal directions. The vehicle was modeled with 9 deg of freedom resulting in a set of 9 simultaneous, second order, differential equations. Numerical integration was effected via the Runge Kutta method with the aid of a digital computer. Output, in the form of a displacement of any point on the vehicle and in either the vertical, lateral, or longitudinal direction plotted against time, could be obtained.

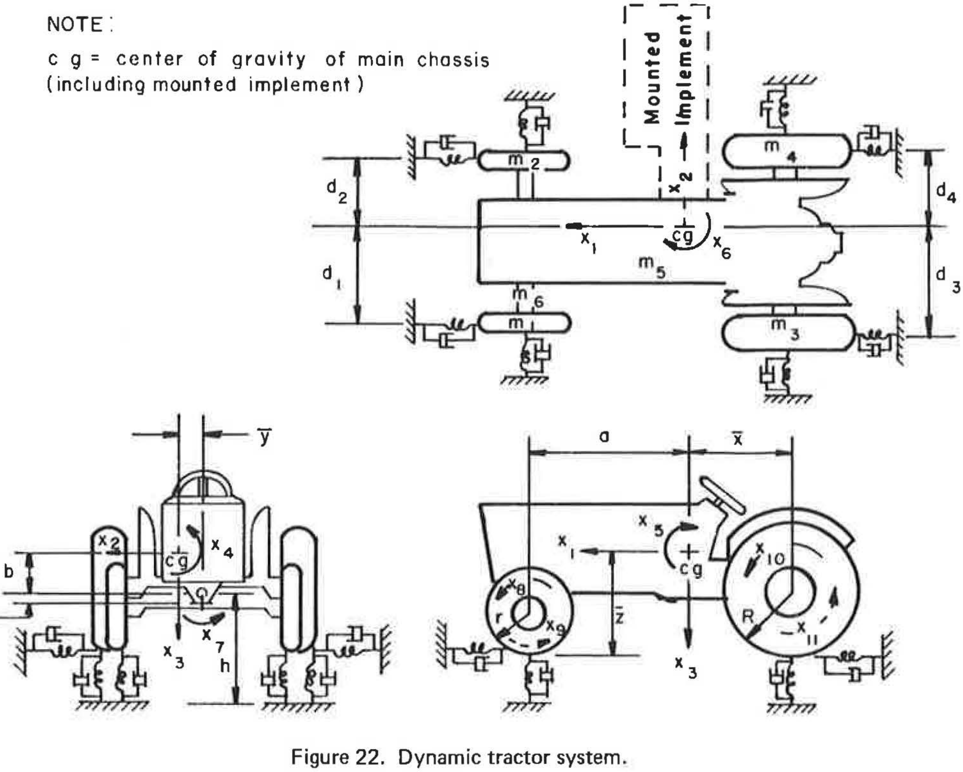

Figure 22. Dynamic tractor system.

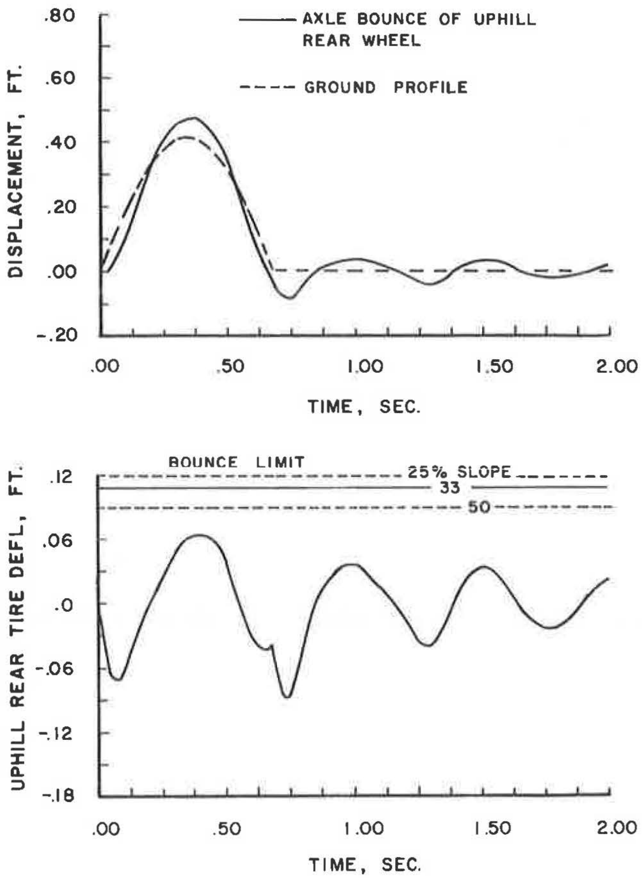

Figure 23. Transient response of tractor for standard conditions.

For all cases studied, the input was in the form of a single bump traversed by the uphill rear wheel. A standard sinusoidal bump having a height of 5 in. and a length of 3 ft was used with forward travel speeds of 3, 4.5, and 6 mph. The tractor that was simulated was dynamically stable on all slopes up to 50 percent when operating at 3 mph over the standard bump (Fig. 23). The tractor wheel lost contact with the ground at 4.5 mph on 25 percent slopes and at 6 mph on flat slopes and was considered to be in an unsafe condition. The ride was improved when spring rates were reduced 50 percent and damping was doubled. This partially illustrates the potential of a separate suspension system between the chassis and the wheels. The addition of a side-mounted implement located on the uphill side improved the stability, even though the actual bounce motion was greater for the conditions studied. There was a considerable difference in the transient response of the tractor modeled with 9 deg of freedom as compared to the more conventional, simplified 3 deg of freedom model. This points to the need for careful consideration in selecting the degrees of freedom for a mathematical model used in simulation.

ACKNOWLEDGMENTS

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