FEASIBILITY STUDY
FOR THE
WINDOW-WALL WASHING SYSTEM
FOR THE
PORT OF NEW YORK AUTHORITY
WORLD TRADE CENTER

File
Window
Washing

180-27

FINAL REPORT

Prepared for

THE PORT OF NEW YORK AUTHORITY
111 EIGHTH AVENUE
NEW YORK, NEW YORK

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AMERICAN MACHINE & FOUNDRY COMPANY
RESEARCH & DEVELOPMENT DIVISION
689 Hope Street
Springdale, Connecticut

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1. SUMMARY

This report summarizes the work performed by The American Machine & Foundry Company under a contract with The Port of New York Authority for Phase I of an automatic window and wall washing system development. This phase, now completed, was an engineering study to determine the feasibility of such a system for the proposed World Trade Center buildings.

Our principal efforts were directed toward the development of feasible system concepts, and their evaluation through a preliminary laboratory test program designed to substantiate some of the major parameters. A survey of existing equipment was part of the program. The conclusions reached in this study are listed below:

1) There is no automatic window-wall cleaning system or apparatus commercially available for use on the W.T.C. towers. The only practical "in-being" system involves manual laborers working from a powered platform such as is built by The Manning & Lewis Company.
2) Laboratory tests have successfully demonstrated the efficacy of a mechanical window washing device. These test results, together with preliminary design analysis, show that the development of an automatic window-wall cleaning system for the World Trade Center is feasible. The system concept is sufficiently flexible so that the

vertical guide tracks may be flush mounted on either the sides or the face of the building columns. The only requirement is that the tracks remain in a single plane for the entire vertical travel and that they extend to the roof line.

3) The total cost for such a system (including the design, fabrication, and test of a usable prototype as described in Phases II and III as well as the construction and installation of the system at the W.T.C.) would be substantially less than the estimated cost of a Manning and Lewis type of powered platform.

4) An automatic system would result in an annual labor cost savings of approximately $88,000 for the W.T.C.

2. STATE OF THE ART

The State of the Art Study which was conducted during the initial phase of this program has shown that there is no automatic window-wall washing device available. We have, however, gathered considerable information on the various types of powered platforms now in use and approved for the purpose of manual window washing on high rise curtain type structures. We have also obtained information on the frequency, method, and labor cost of washing the windows of some of the newer curtain wall buildings in the New York area.

Three types of powered platforms are used for manual window washing and light maintenance work. The first of these is suspended on cables which are played out from drums on a hoist trolley located at the roof[1]. The second type[2] has a hoist motor and cable drum located on the platform itself so that with the cable attached to either the roof structure or a roof trolley the platform pulls itself up by collecting cable as it travels upward, playing cable out as it descends. The third type[3] is similar to the second in that the hoist motor is mounted on the platform which rides on but does not collect the cables.

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[1] The majority of buildings in the New York area taller than 30 floors have this type and all of these have been made by The Manning & Lewis Co.

[2] Spider Staging, Inc. is a typical manufacturer.

[3] Western Gear Corp. is a typical manufacturer.

As the platform ascends, the cable hangs freely below the platform possibly secured at the lower end.

Of these, only the Manning and Lewis system would be applicable to the World Trade Center Buildings. The tower height eliminates each of the last two systems described, since each is restricted[4] to a maximum of 500 to 600 feet of vertical travel.

The capital investment cost[5] for the Manning & Lewis system is plotted as a function of number of floors serviced in Figure 1. If the data is extrapolated as shown, this type of system would have an estimated cost of approximately $800,000 for each of the two W.T.C. towers. Inclusion of the rails and support structure required on the roof brings this figure to the neighborhood of $1,000,000.

In order to make an economic comparison of automatic and manual window cleaning operations, labor cost[6] estimates are listed in Chart A. These data are plotted as a function of total window surface area in Figure 2. This shows that approximately 120 man-days would be required to clean the 260,000 square feet of windows in each of the W.T.C. towers. Assuming that the windows are cleaned once a month, we arrive at a yearly labor cost[6] of approximately $54,000 for the manual cleaning operation.

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[4]This restriction is imposed by the limit on the length of the power line which must be dropped to the platform.

[5]These figures are estimates obtained in confidence from the Managers of those buildings listed.

[6]These cost figures were arrived at using $27/day for direct labor and $9/day for fringe benefits, insurance, etc. These figures are conservative since they do not include the building maintenance company's overhead or profit.

A survey of existing and potential cleaning methods which might be employed in an automatic window cleaner, indicates the following possibilities:

1) <u>Liquid Cleaner.</u>
2) <u>Abrasive Action</u> with a fine particle substance.
3) <u>Ultrasonic Vibration.</u>
4) <u>Electrostatics.</u>
5) <u>Flame Cleaning.</u>

The recommendations of the principal glass manufacturers we have contacted discount all but the first of these methods. Similarly, individuals in the building maintenance field as well as our own Physicists and chemists favor the use of a liquid cleaner (preferably water base). We have, therefore, concentrated our efforts on a scheme which would duplicate the manual window cleaning operation using a liquid cleaner. It was felt that only if this proven method should not be adaptable to an automated system, would it be justified to explore any of the "exotic", more complex methods.

3. SYSTEM CONCEPT

3.1 Operational Description

The automatic window-wall cleaning system which has evolved in this study consists of a cab which traverses the face of the building by means of a dual cable support suspended from a hoist trolley located on the roof.

The hoist trolley is mounted on roof tracks which run parallel to the face of the building with a turntable located at each of the building corners as shown in Figure 3. The window washing operation will begin with a manually supervised engagement of the cab on the building face. This will be accomplished with the hoist trolley located on the turntable and the cab in the service-start position as shown in Figure 4. First the cab will be raised to the hoist arm while the lower portion of the guide tracks pivots 90° to the horizontal position. The entire hoist arm assembly will then be raised (so that it can clear the roof parapet), and the turntable will rotate 180° to bring the cab in line with the face of the building (Figure 5). The cab will be lowered as the guide tracks are pivoted downward 90° to the vertical position. When the cab has traveled to the bottom of the hoist guide tracks, the entire hoist arm structure will be lowered into the hoist trolley (Figure 6). At this time, the horizontal index wheel located at the bottom of the guide track extension engages the horizontal transfer track. Now the hoist trolley may be moved to any of the window column locations on this side of the building. This completes the supervised portion of the operation until six of the window columns (from the 106 to the 7th floors) have been washed, at which time the cab will automatically stop at the horizontal transfer track to await supervised operation.

On command, the automatic cycle will begin with the cab traveling down to the top most window where it will stop and the washing module will be extended from the cab (Figure 7 and Figure 8), to come in contact with the window surface. Upon extension of the washing module, the wash motor driving the brushes and squeegee (if driven) will be energized and the cab will be lowered at a constant speed of approximately 25 ft./min. At each of the mechanical floors (to accommodate the change in cross section of the structural columns as shown in Figure 7) the cab will stop to retract the washing module. After passing each of the mechanical floors the cab will again stop, extend its washing module, and continue its downward traverse. When it reaches the bottom of its stroke (the 7th floor) it will retract the module and reverse its direction, traveling nonstop to the roof at a speed of 100 ft./min.

The round trip time for a single column will be approximately 1.1 hours including the time for each of the four momentary stops. When the cab reaches the horizontal transfer track it will stop (Figure 9), and the hoist trolley will automatically[7] be indexed to the

[7] The control system could be simplified by having the cab stop whenever a single column has been completed, and by having an attendant accomplish the horizontal indexing to the next window column.

next window column location where the cab will start on its second round trip of a window column. The cycle time for a single column, including the periods required for each of the four momentary stops and for the horizontal transfer, will be approximately 1.2 hours. Upon completion of the sixth window column (in about 7.2 hours) the cab will stop automatically at the horizontal transfer track and await supervised removal from the building face for servicing. Removal of the cab will be accomplished in a sequence of operations opposite to those for the cab placement. The hoist arm structure will be raised by means of the cylinder telescoped from the hoist trolley. Thus, the horizontal indexing wheel will be disengaged from the horizontal transfer track. The cab will be lifted to the top most portion of the hoist guide tracks pivoting the track extension as it does so. The hoist trolley will then be driven to either end of the building side where it will run onto a turntable. The table will be rotated, bringing the cab onto the roof. It may then be lowered to roof level for servicing and/or maintenance.

Assuming that the system will be in operation for only one eight hour shift per day, two such cabs (each with a hoist trolley) would be required to wash the windows of each of the towers in 20 working days each month (Appendix A).

To meet the requirement for cleaning of the building face once a year, a wall cleaning cab will replace the window cab on the hoist trolley. Thereafter, the operational procedure will be the same as described above[8]. To accommodate the corners of the building, the trolley will be put on the turntables and rotated until the cab is in line with the corner face. (This will be a supervised operation). With outriggers on the standard wall cleaning cab the corner face can be cleaned in a single pass. Since the wall cleaning operation may require 20 working days[9], and since the window and wall cleaning operations cannot be performed simultaneously, the system must operate two shifts per day for one month every year to avoid interrupting the monthly window cleaning cycle.

The requirement for a manned cab may be met with a cab of the same overall configuration as the window washing cab without its internal components. During the manned cab operation, an operator would be stationed at the hoist trolley for manual control of the system. Some means of communication could be provided between the trolley operator and the man in the cab.

<u>3.2 Equipment Description</u>

1. <u>Hoist Trolley.</u> The hoist trolley or roof car will be approximately 8 feet long, 4 feet wide, and 7 feet high (Figures 3 & 4), and will have a total weight of about 6000 pounds fully loaded. (We would like to make the trolley 8 feet wide for better stability, but this would require an architectural change as described on Page 17). It

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[8] The cab velocity on the down or cleaning stroke may not necessarily be 25 ft./min.

[9] Assuming the same period as required for a complete building window washing cycle.

will contain the following components:

a) Hoist motor (approx. 4 H.P.).

b) Two cable take-up drums[10] (3-1/2 ft. diameter, 3-3/4 ft. long).

c) Gear Train.

d) Brakes.

e) Hoist arm telescoping system.

f) Automatic control system and panel (with manual override).

g) Trolley motive system.

The only requirement for an external electrical connection from the building to the trolley is in the primary power supply for the hoist motor, trolley motive system, and automatic control system. There will be no requirement for electrical connections or controls to either the face of the building or to the cab. Control of the vertical motion of the cab may be accomplished with a limit switch system controlling the hoist motor, while the horizontal transfer might be performed by means of the horizontal indexing wheel which could sense depressions in the horizontal track at the column locations.

2. Cab. Three cab configurations will be required: Window cleaning, wall cleaning, manned maintenance. Although the three configurations are within a single envelope size, it would be more feasible to have separate cabs for each operation, rather than re-working a single cab to each of the configurations when required. Thus,

[10] These will be grooved single wrap drums, each capable of holding 1300 feet of cable.

the number of cabs per building might total 6-8:

a) Window Washer Cab - 2 operating, 1 or 2 in reserve.

b) Wall Washer - 2.

c) Manned Module - 1 or 2.

The cab will be completely independent, containing sufficient electrical power and liquid cleaner supply for an 8 hour uninterrupted operating period (Appendix A). The signal required to extend or retract the washing module (also starting or stopping the washing mechanism motor, respectively) will be supplied by means of a mechanical trip located, possibly, in the tracks.

The cab will be supported by cables which will be contained in the vertical guide tracks. (We feel that this containment is mandatory otherwise the cables would be free to whip on the building face). The window washing cab configuration presented in Figure 10 shows the wash module in the extended or wash position. The test and indicator panel would contain the electrical connector for charging the batteries, a liquid level indicator, and possibly some test points for easy checkout of the electrical system. The filler cap shown at the top of the cab would be removed for refilling the liquid cleaner storage tanks. The test panel and filler cap would be purposely made easily accessible so that the servicing function may be performed either from the mechanical floors or on the roof.

Figure 11 contains another schematic of the cab, this one showing component location and weight approximations. Four lead acid storage batteries having a combined weight of 250[11] pounds would be wired in a series-parallel circuit (Appendix A). The drive motor (20 pounds) would be located at the module pivot point, thus minimizing the forces required to extend and retract the wash module (50 pounds). Two five gallon liquid storage tanks (80 pounds when full) are located symmetrically. Both would feed the wash module simultaneously through a float valve so that as the liquid is used the cab center of gravity will remain equidistant between the support cables. Thus, the loads transmitted to the building and the tendency for the cab to cock in the tracks will be minimized.

Estimating the cab structure at about 100 pounds, we arrive at an initial operating weight of 500 pounds for the cab. In addition to this, when the cab is at the bottom of its travel (at the 7th floor) there will be another 250 pounds of cable bringing the total weight which must be supported by the hoist trolley to 750 pounds.

The approximate size of the cab will be 5 feet wide by 1-1/2 feet deep by 2-1/2 feet high. The storage batteries and liquid storage tanks will be fixed components possibly mounted on rollers or slides for easy maintenance. The wash module (containing the wash brushes and squeegees, motor, circulating tank, filter, etc.) will be extendible from the cab as previously described with the liquid cleaner and electrical power supplied from the cab to the module through a flexible umbilical line.

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[11] We have also investigated the possibility of using a lighter weight D.C. power supply such as Nickel Cadmium and Silver Zinc, but they would be more costly and have a shorter life.

The guide rollers at each of the four support points (Figure 10) must be capable of resisting lateral loads in two directions. Details of two possible guide support schemes with plan views of the track required are shown in Figures 12 and 13. Scheme A shows inside track dimensions of 1-1/4 inches x 2 inches and scheme B shows 1-1/4 inches x 1-11/16 inches.

Although we have shown the guide tracks as being located at the centerline of each of the column faces, our system is adaptable to tracks mounted on the sides of the columns. A possible track configuration is shown in Figure 14. Our only requirements are that wherever the track location, it must be continuous, remain in the same plane, and extend to the roof line (to meet the horizontal indexing track). If it is mounted on the column side, for reasons of stability and mechanical design, it should be as close to the column corner as is possible (Figure 14).

From a design standpoint, our preference is to locate the tracks at the column face. Considering the economics of the two locations, approximately 300,000 linear feet of track per building is required at the column face and twice this amount for the column side location.

3.3 Structural Loads

The structural loads transmitted by the system to the face and roof of the building are minimal and thus offer no problems to either the building or system design. The loads resulting from normal operating conditions are shown in Figure 15. The 500 pound maximum cab weight is shown equally distributed between the two support cables. Since the cab center of gravity is equidistant from the support points, there are no side loads (frontal view). To balance the moment due to the 500 pound weight load there will be forces of 143 pounds into and out of the building (through the tracks) at the four support points.

In addition to the normal operating loads we have superimposed a high wind condition (Figure 16). Arbitrarily selecting a maximum wind velocity of 100 miles per hour (which results in a 0.4 lb./in.^{2} side force on the cab), the induced loads are still very reasonable, the maximum being 178 pounds.

For the ultimate in cab loading conditions, we have investigated the situation in which one of the cables is sheared and the entire weight load of 500 pounds must be taken in the remaining support cable (Figure 17). This is by far the most severe loading condition resulting in a side load of 464 pounds superimposed on the 143 pound load perpendicular to the building face. As far as the cable is concerned, if we assume that the cable must support the 500 pound weight load plus its own weight of 125 pounds (if the failure occurred at the lower floors), a 1/4 inch diameter cable which can withstand a maximum load of 5,000 pounds would still have a factor of safety of 8 (Appendix A).

A static loading diagram of the hoist trolley is shown in Figure 18. With a 1,000 pound load (for the cab in the fully extended position) at the end of the hoist arm, and with an estimated 6,000 pounds for the trolley and its components, the reaction load at B (the outer roof rail) is, 6,250 pounds and at A 750 pounds. Thus, the trolley is stable in this plane. As an added safety margin the trolley should grip the inner rail in a positive manner to eliminate all possibility of tilting. The maximum roof loads, which occur at the building corners, (as shown in Figure 2) amount to 12,000 pounds.

Distributing this over a 10 foot diameter turntable, we arrive at 153 lb./ft.^{2} roof loading. When the trolley is operating away from the corners this would be reduced to approximately 125 lb./ft.^{2}.

3.4 System Maintenance & Servicing

The hoist trolley should require no extraordinary maintenance or servicing beyond that which is required by the State and City Codes for a powered lift of this type[12]. The most important requirements defined are the changing of the hoist cables every eighteen months and the periodic inspection of the system by a professional engineer who is familiar with this type of equipment.

A daily servicing routine of the cab will be required. This will entail filling the liquid cleaner storage tank and making a simple plug-in connection from the electrical charger to the cab for overnight charging of the batteries. This procedure should require no more than a half hour. Thus, for daily operation one man per building should be sufficient for servicing the two cabs and operating the hoist trolley for placement and removal of the cabs at the beginning and end of the working shift, respectively.

As an alternate procedure to the daily placement of the cabs, we can suggest that the system be designed to stop the cab automatically at one of the mechanical floors at the end of each day. Here it can

[12] There are no such codes for an unmanned powered platform, but we assume that they should not be more stringent than those for the manned powered platforms.

easily be serviced in the manner described above, remaining stationary on the face of the building overnight.

Periodically other components of the cab and washing module will have to be replaced because of wear and operating life. An estimate of these is as follows:

1) Squeegees - Once a week.
2) Brushes - Once a month.
3) Batteries - Once a year.
4) Cleaning & Preventive Maintenance - Once a year.

The cab and module must be designed for ease of maintenance and servicing so that all of the above can be replaced with a minimum of effort. We do, however, recommend the use of spare cab(s)[13] to avoid down time, should serious maintenance problems arise.

3.5 Architectural Modifications

The system concept has been designed with a minimum number of architectural alterations so as not to disturb the overall building aesthetics. The vertical guide tracks are shown on the face of the columns in order to accommodate the widening of the columns at the mechanical floors. The guide rails could be installed on the sides of the columns if this widening could be eliminated, and if these tracks could be extended to the roof line.

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[13] Since the cost of the cab will be relatively low, the additional cost of spare cabs will not affect the economics of the total system appreciably.

The face tracks would require the removal of the decorative channels on the column faces at each of the mechanical floors. Although it is theoretically feasible to design around these protrusions by various schemes, excessive structural and/or operating complexities are involved.

The wheel base of the hoist trolley is shown as just under 4 feet. This dimension was determined by the limitation imposed by the wall supporting the roof parapet (Figure 5) in the extreme corner positions of the trolley. Thus, the length to width ratio of the cab (4 to 8) is 1/2, which is less than the recommended value for stability. If the wall can be cut out at the building corners, the width of the cab could be increased to 8 feet, giving a ratio of 1. At the same time horizontal wheels could be used below the rail flanges to prevent cocking of the trolley.

The remaining architectural modifications are less demanding. Our system would require the extension of the guide tracks to the roof line[14] (Figure 9) and the addition of a horizontal track at the base of the parapet (Figure 9). In order to accomplish the wall cleaning of the building corners, two vertical guide tracks will be required at the building corner face[15], each being structurally tied to the single corner column (Figure 9). Similarly, on the corner face at the roof line some local relief at the base of the parapet is required

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[14] The preliminary architectural drawings with which we have been working are prefixed with designation AY-PPR-2.

[15] Design of building corner cleaning equipment would be seriously complicated if these tracks are not architecturally permissible.

to allow installation of a horizontal track (Figure 9). In order to minimize wear of wash brushes and squeegees, the transition between the spandrel and the window surfaces should be as smooth as possible; rounding or chamfering the horizontal edges of any protruding members would be desirable.

Keeping the cab as small as possible results in minimum detraction from the architectural aesthetics of the building (Figure 6) during operation. To further this effect the skin of the cab should be made of the same material as the building face. Similarly the protrusion of the hoist trolley above the parapet during both the operating and servicing modes is kept at a minimum.

3.6 Economic Analysis

Although a detailed cost analysis of the system as described has not yet been made, we feel that such a system can be put into operation for a cost competitive with that of a Manning & Lewis type platform as described in the State of the Art Study. This would include the design, fabrication and testing of a full scale prototype as described in Phases II and III of the program.

The most attractive economic feature of the automatic system is, of course, the labor cost savings. If we allow $9,000 for the labor cost (one man-year @ $36/day) and $1,000 for the maintenance replacement cost (batteries, etc.), we arrive at a cost savings of $44,000 per year per building.

FIGURE 21. WASH MECHANISM SCHEME A.

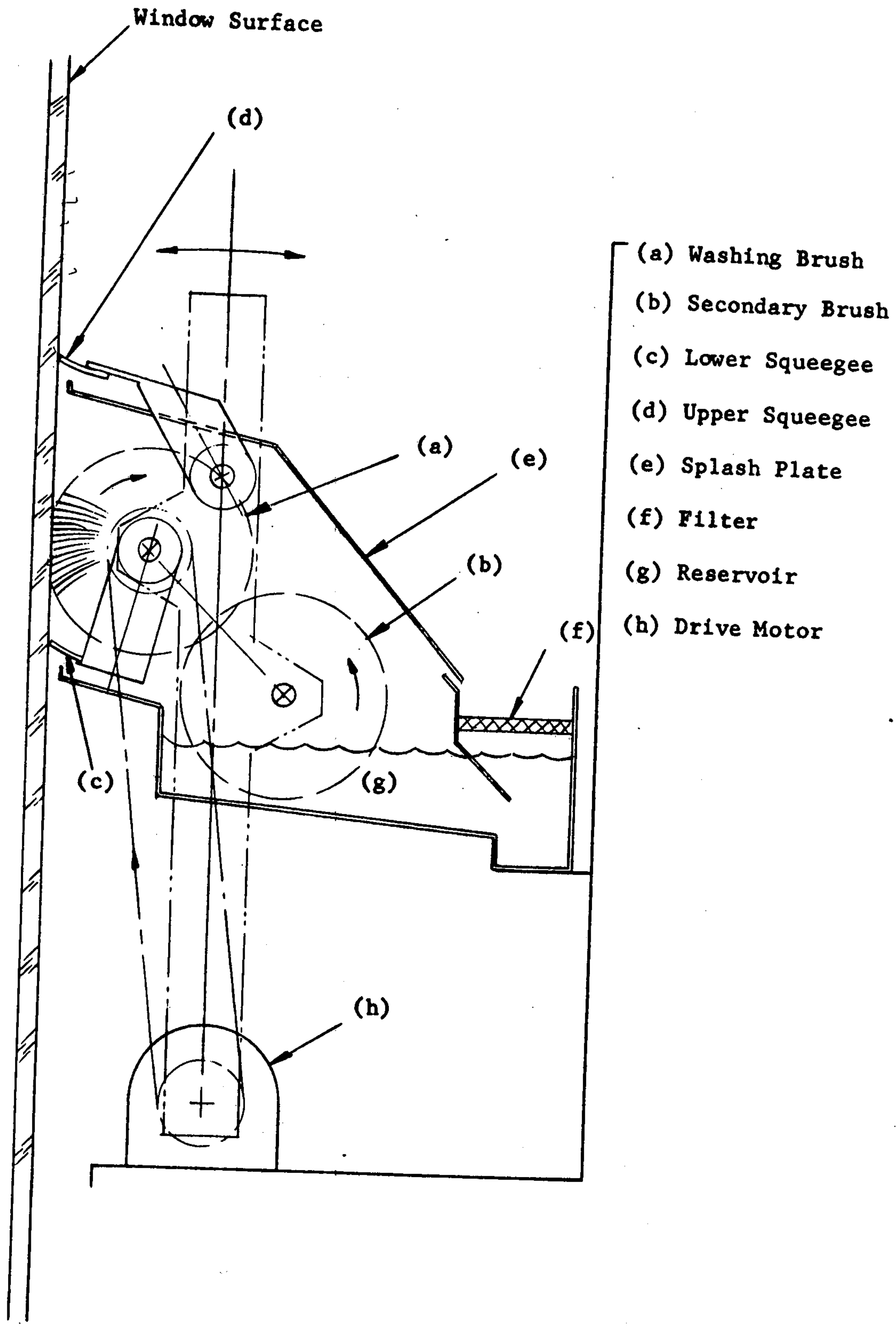
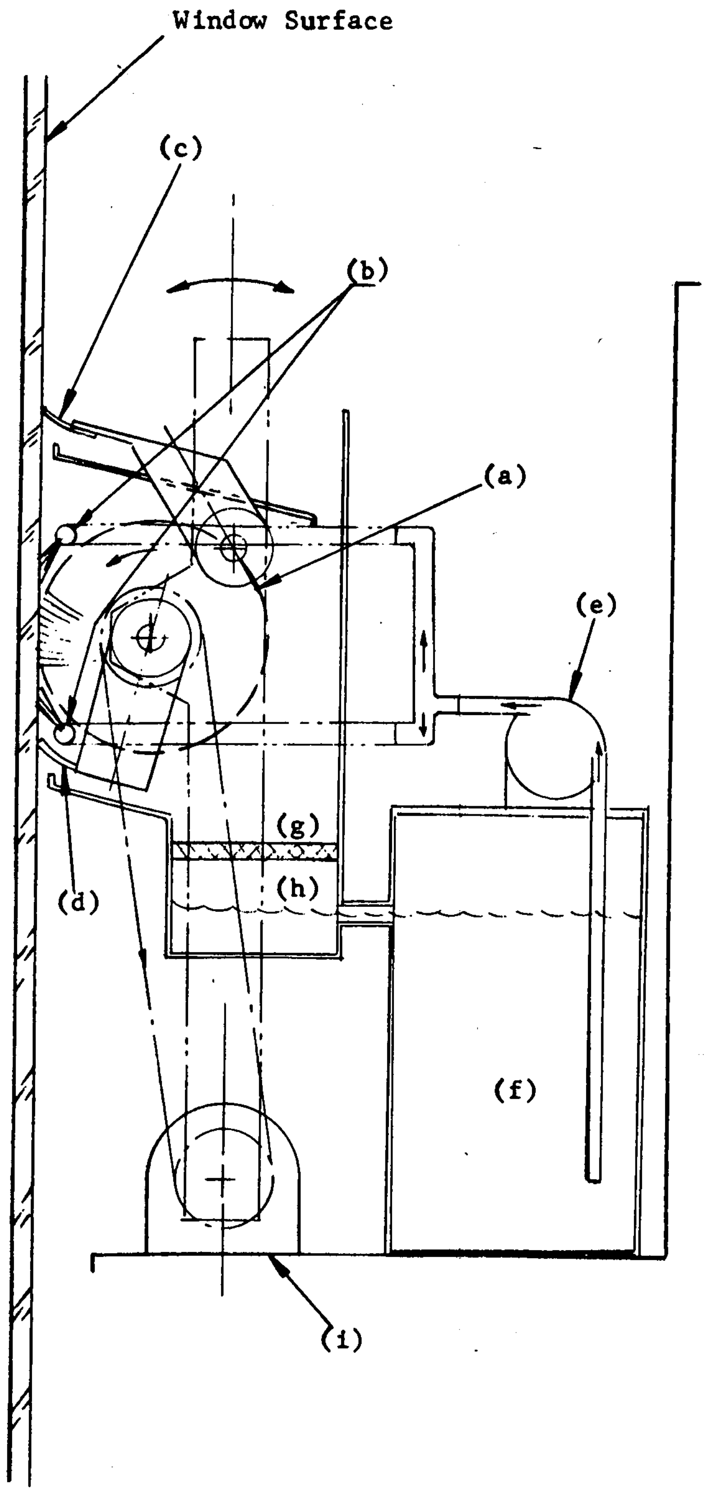
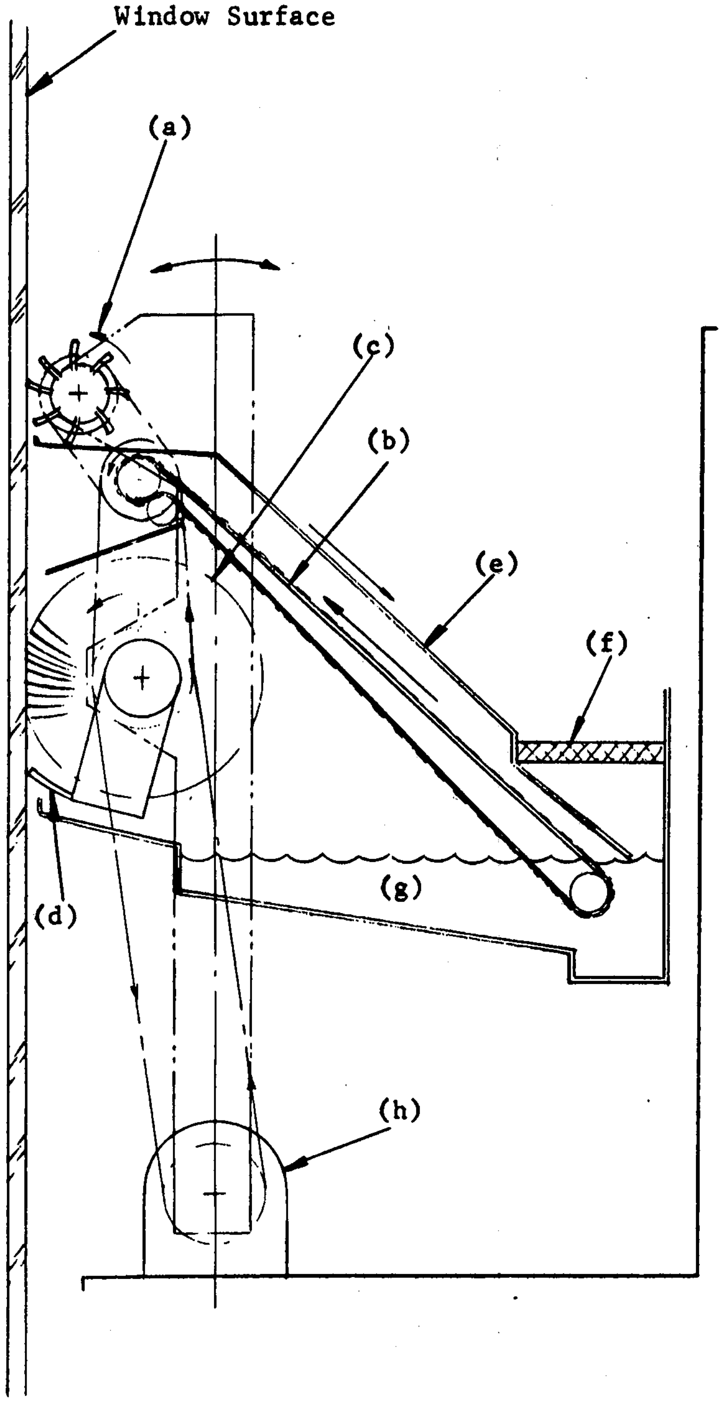


FIGURE 22. WASH MECHANISM SCHEME B.



(a) Washing Brush
(b) Spray Nozzles
(c) Upper Squeegee
(d) Lower Squeegee
(e) Liquid Pump
(f) Storage Tank
(g) Filter
(h) Settling Tank
(i) Drive Motor

FIGURE 23. WASH MECHANISM SCHEME C.



(a) Rotating Squeegee
(b) Porous Belt
(c) Washer Brush
(d) Lower Squeegee
(e) Splash Plate
(f) Filter
(g) Reservoir
(h) Drive Motor

FIGURE 24. FORMULA FOR STANDARD WINDOW DIRT

MAILING ADDRESS: WHITE PLAINS, N.Y.
TELEPHONE: 914 ME 1-6400

GENERAL FOODS CORPORATION / *Technical Center, Tarrytown, N.Y.*
CORPORATE RESEARCH DEPARTMENT

December 21, 1964

Dr. Gregory Laserson
Manager, Mechanical Development Laboratory
American Machine and Foundry
689 Hope Street
Springdale, Connecticut

Dear Dr. Laserson:

Mr. Ludington asked me if I would give you whatever information I could about standard window soils. The following formula gives a soil which is reasonably tenacious.

Component #1

500 cc H_2O	1.25 g starch
1 cc NH_4OH	1.25 g dried egg white
8 drops oleic-linoleic acid	1.25 g dried egg yolk
2.5 cc kerosene	1.25 g $CaCO_3$ (powdered)
2.5 g lard	1.25 g lampblack
1.25 cc linseed oil	1.25 g gum arabic
1.0 cc formaldehyde	

The nonaqueous components were added in the order listed to 250 cc water in a Waring Blendor and the final mixture was then diluted with 250 cc water.

Component #2

4 grams top soil (-30 mesh) is suspended in 100 cc of water in which 0.2 grams of sucrose is dissolved.

The test soil consists of 20% of Component #1 and 80% of Component #2. The soil is applied by spraying, and a DeVilbiss paint sprayer with a suction feed has been found satisfactory.

I hope the above information will be satisfactory.

Yours very truly,

W. M. Tucker
New Products Planning Coordinator

WMT:emm
cc: Mr. V. D. Ludington