Flexible magazine operation and cellular techniques in automation systems

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There is a strong current trend in automation towards systems that can handle small to medium batch numbers. These batch sizes are also often associated with high complexity often in prototyping situations.

The application described is for British Airways Catering at Heathrow Airport where the number of variations in assembly pattern of their meal trays is large. The batch size of each of the assembly variations is also extremely variable.

This thesis describes the justification and design of an automatic system to assemble these trays whilst retaining the flexibiltiy inherent in the current manual assembly arrangement. The work examines system layouts, considering each possibility particularly from the flexibility and potential reliability aspects. This leads to the consideration of industrial robots because of their inherent flexibility. Consequently, the various configurations of robots are examined to assess the suitability of each in a cell arrangement, the system which was chosen for its potential reliability. The work continues by developing the ideas and techniques of parts feeding to realise the maximum benefits from a robotic cell system.

The thesis describes novel magazining arrangements for handling each of the items which make up the tray assembly. Two major developments are described, one for the handling of stackable items and the other for handling small discrete parts from bulk. Both systems are flexible to accomodate variations in part dimensions and possess ability to be quickly re-configured to handle completely different parts.

The equipment designed and constructed for British Airways uses ideas that could also find use in many similar applications where the components have the same characteristics.

Flexible magazine operation and cellular techniques in automation systems.

A thesis presented for the Degree of

Doctor of Philosophy.

By

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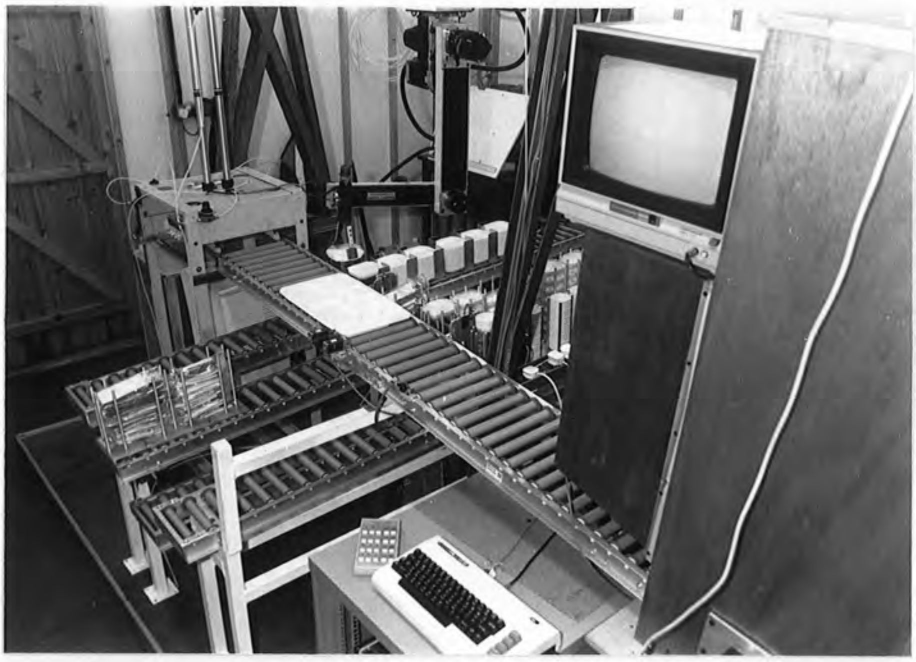

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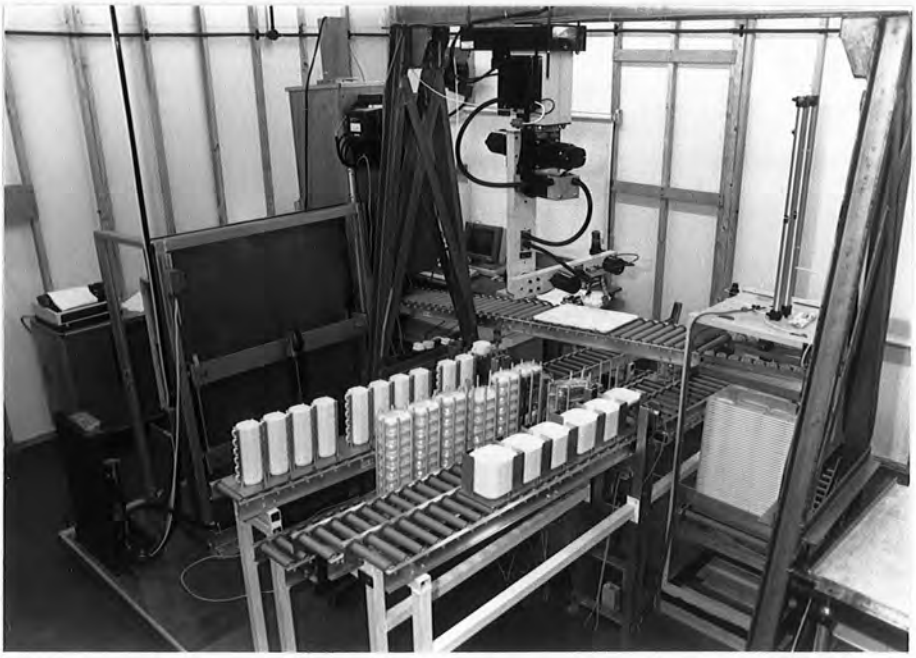

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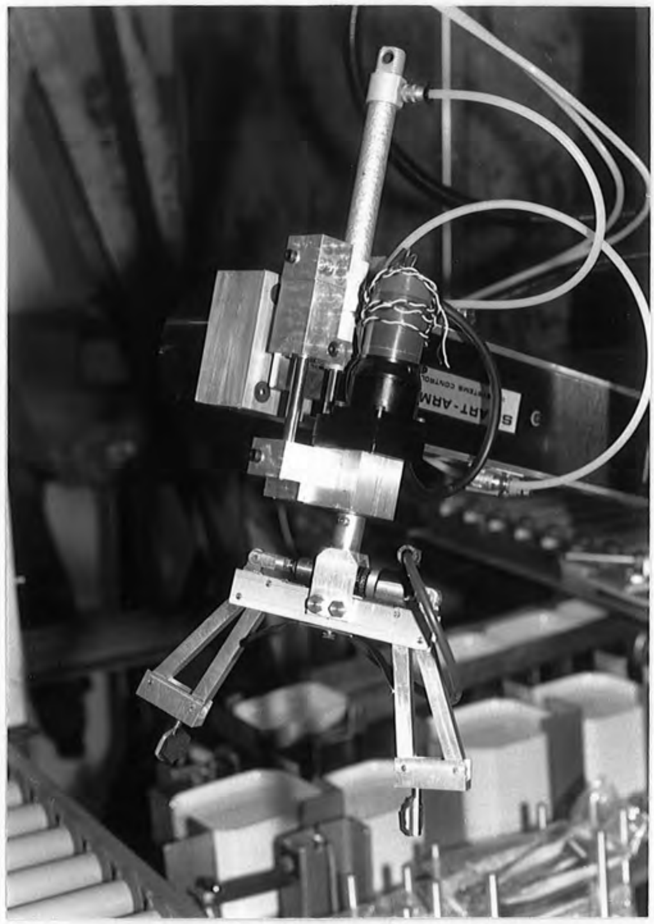

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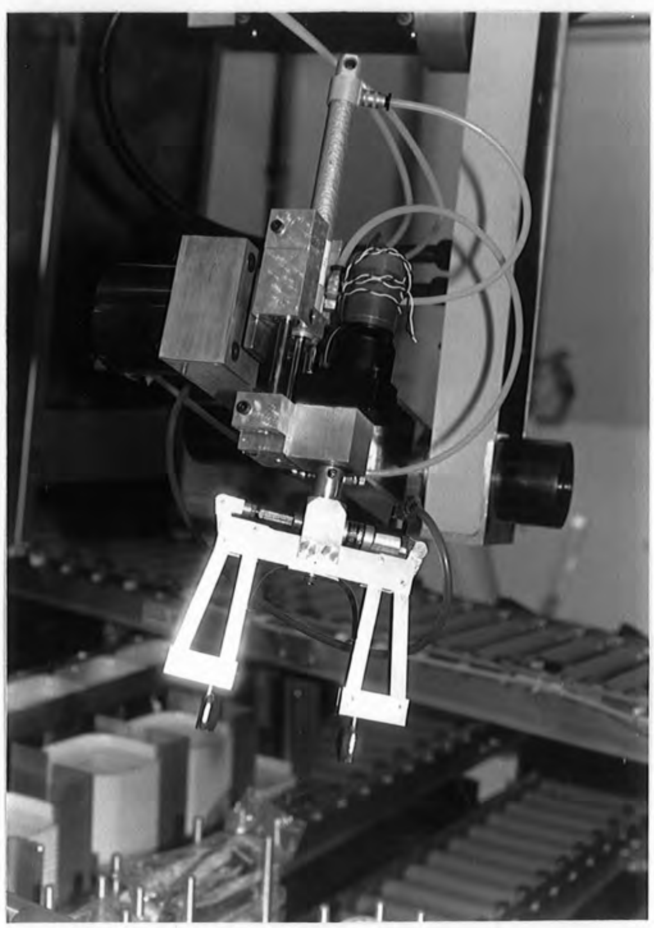

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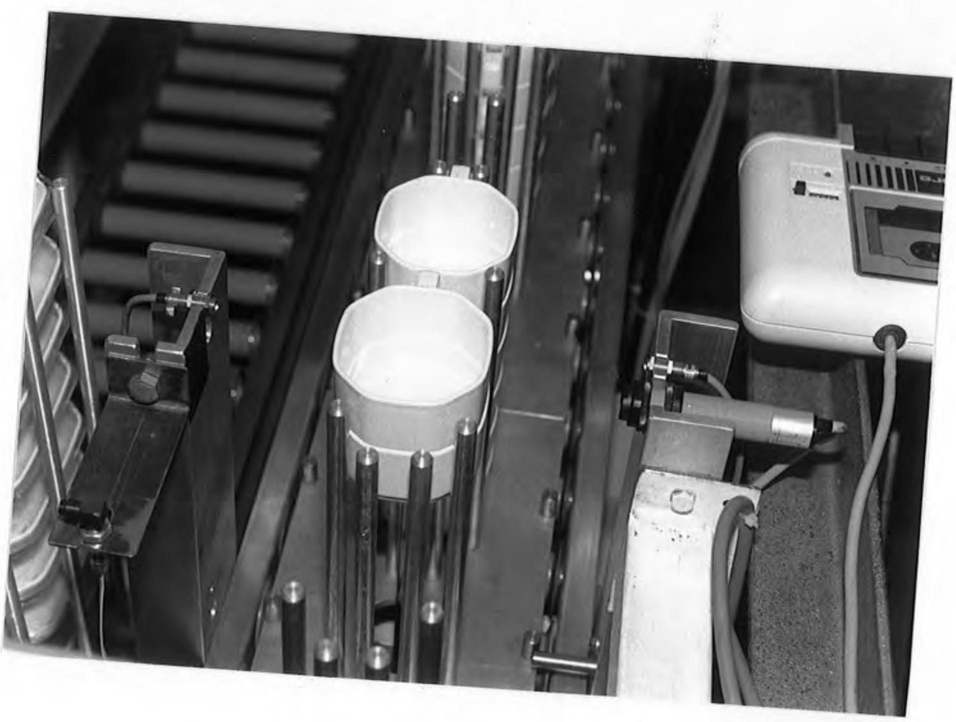

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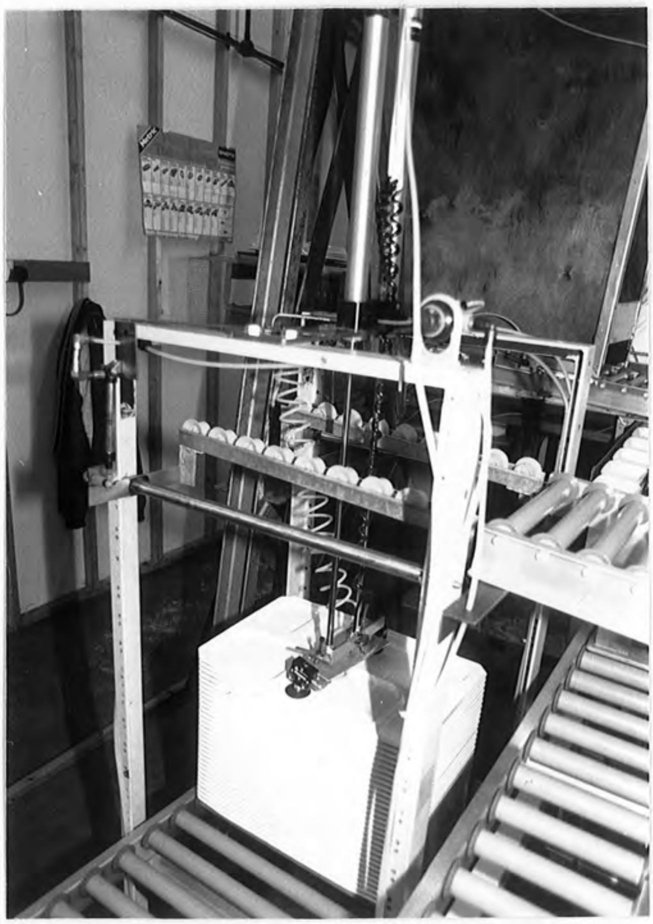

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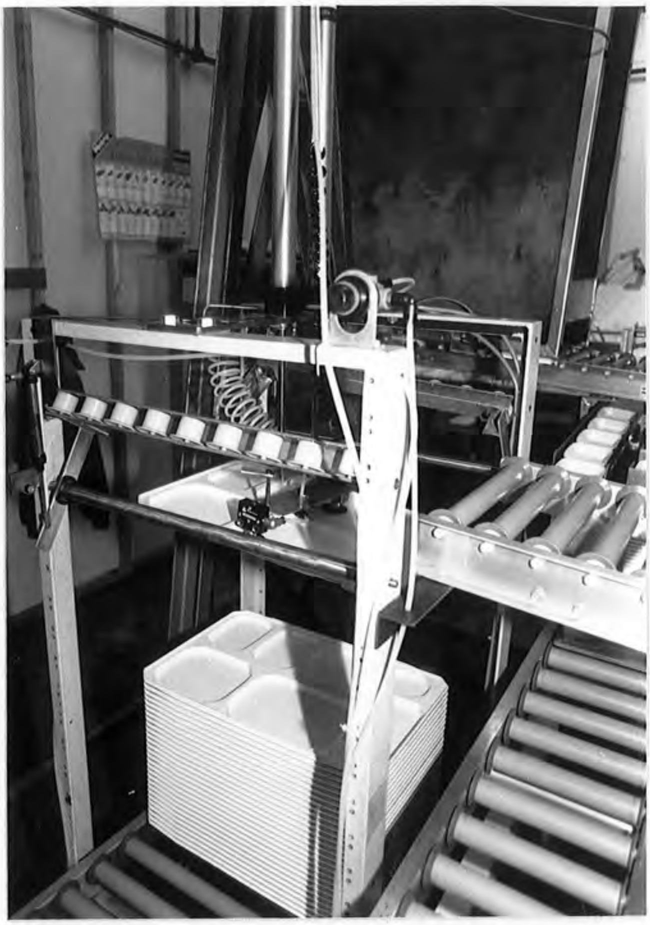

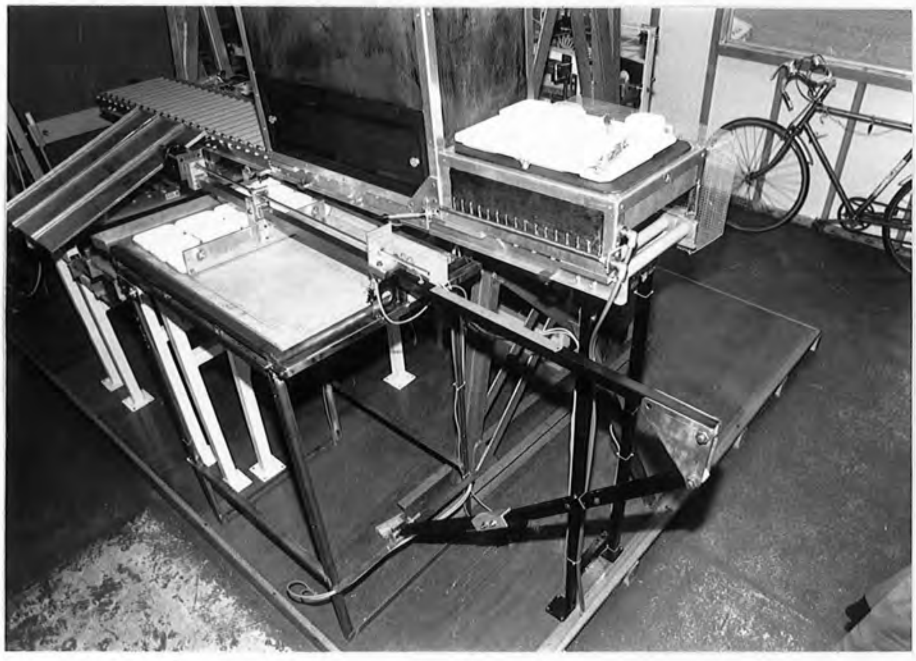

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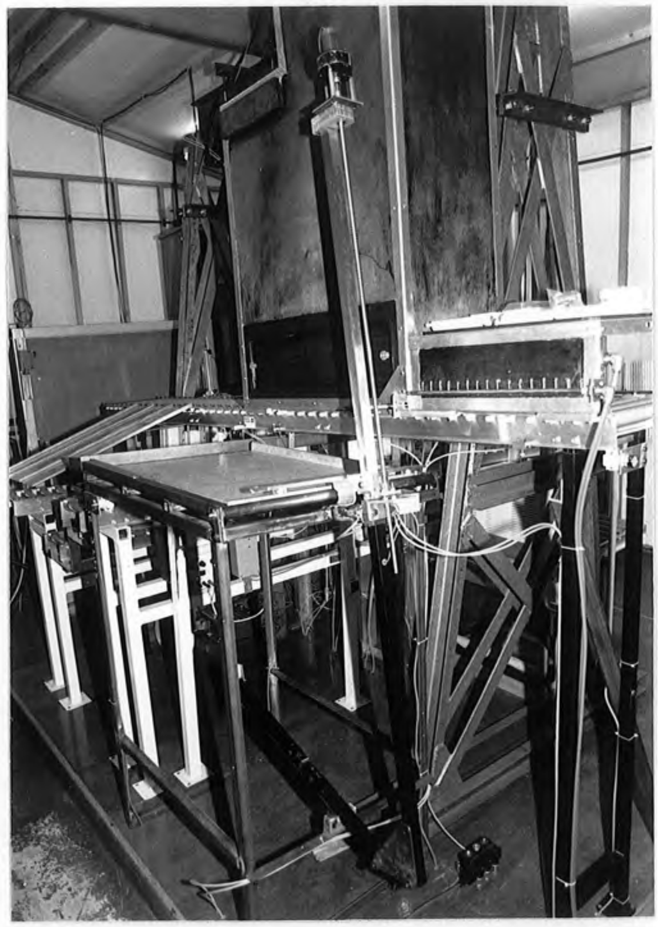

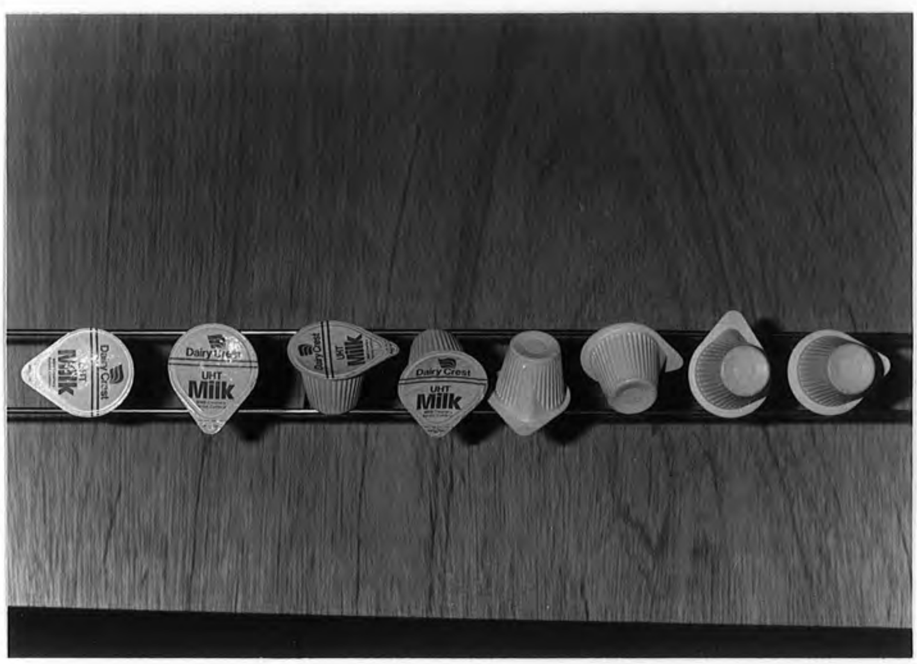

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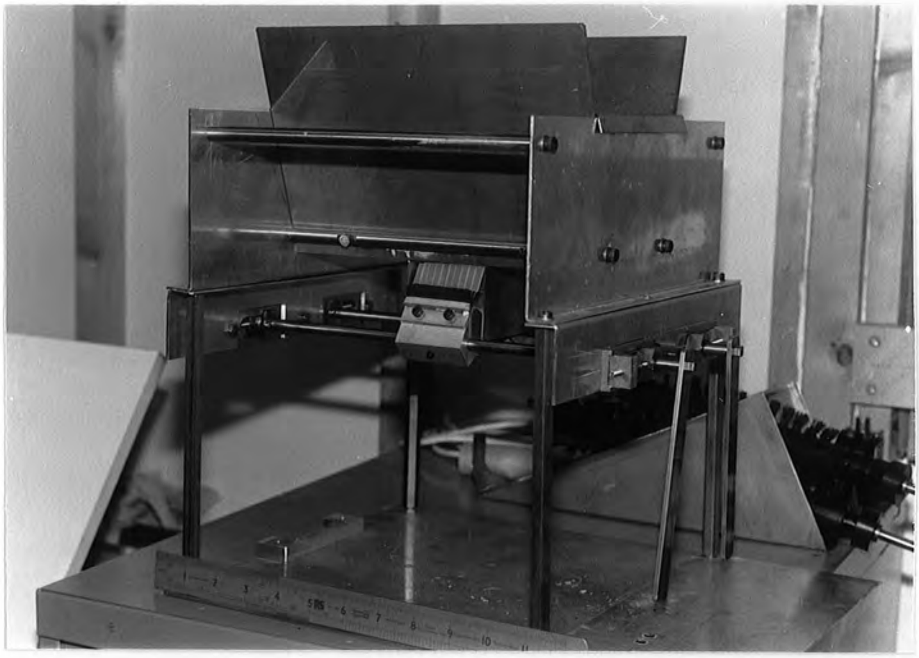

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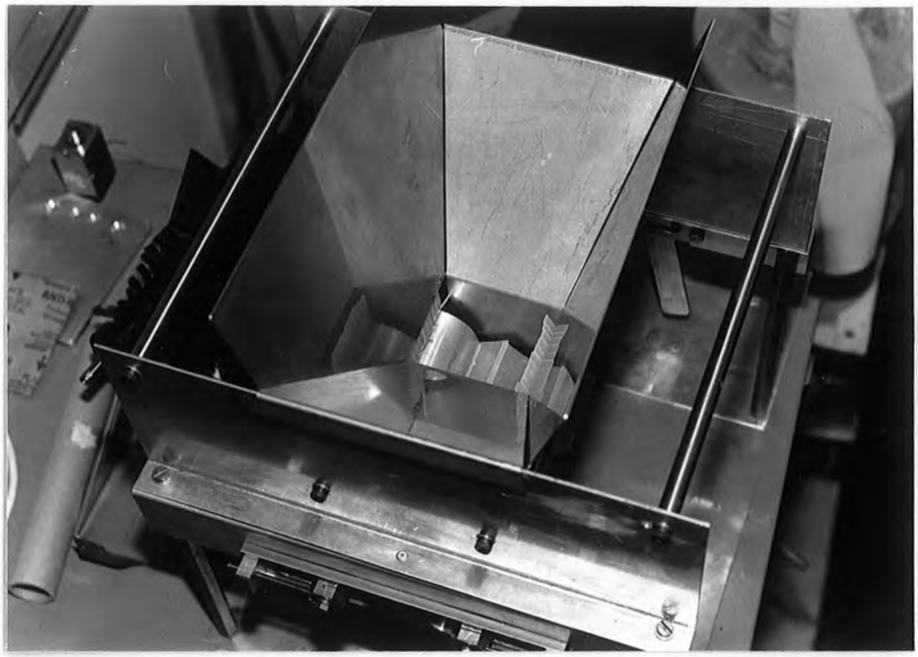

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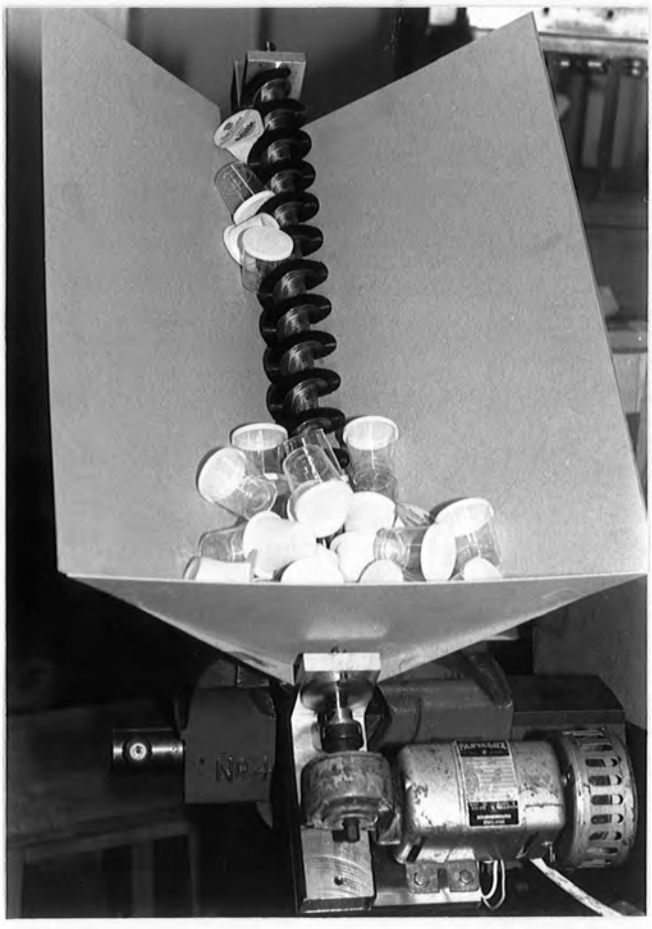

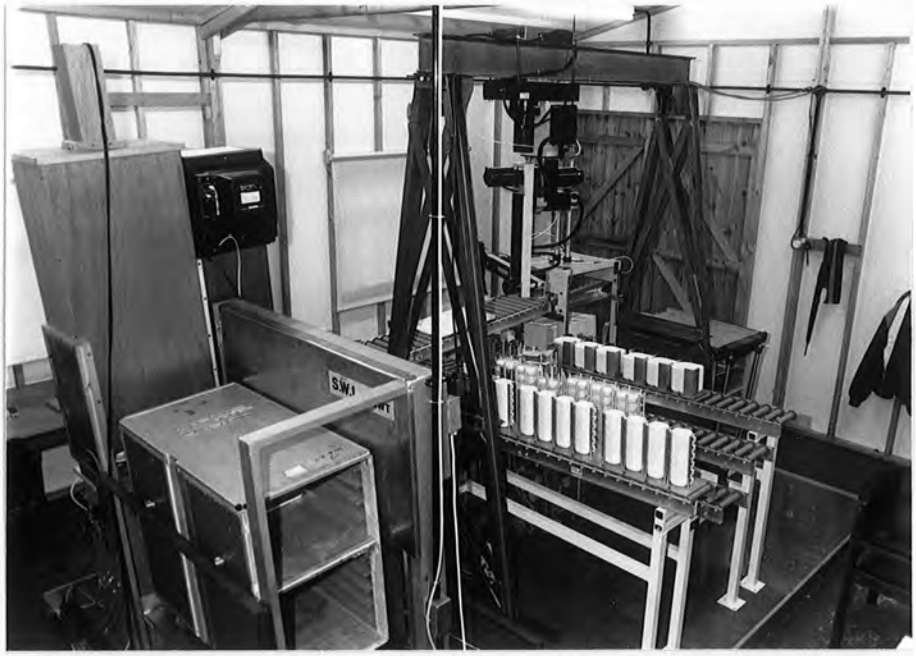

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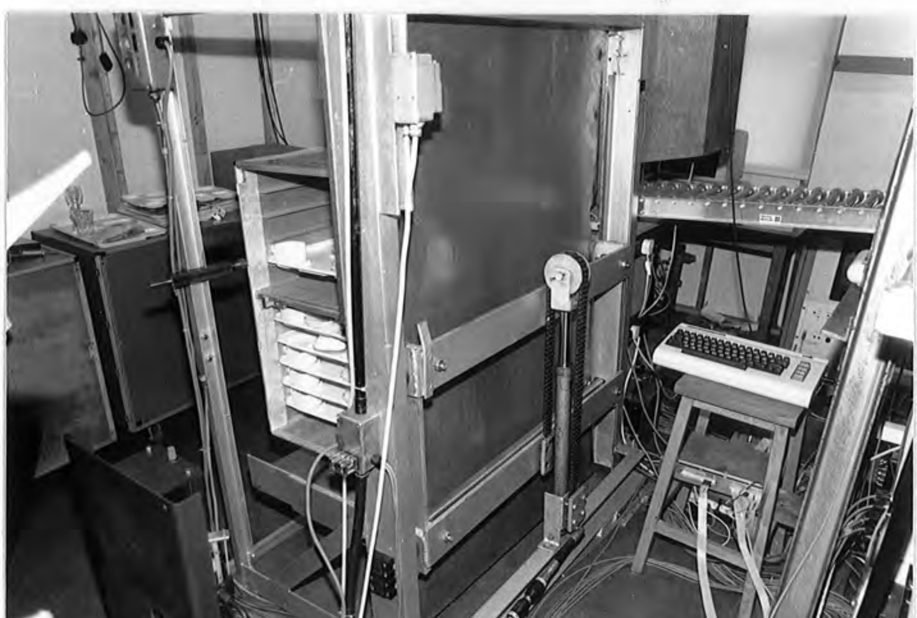

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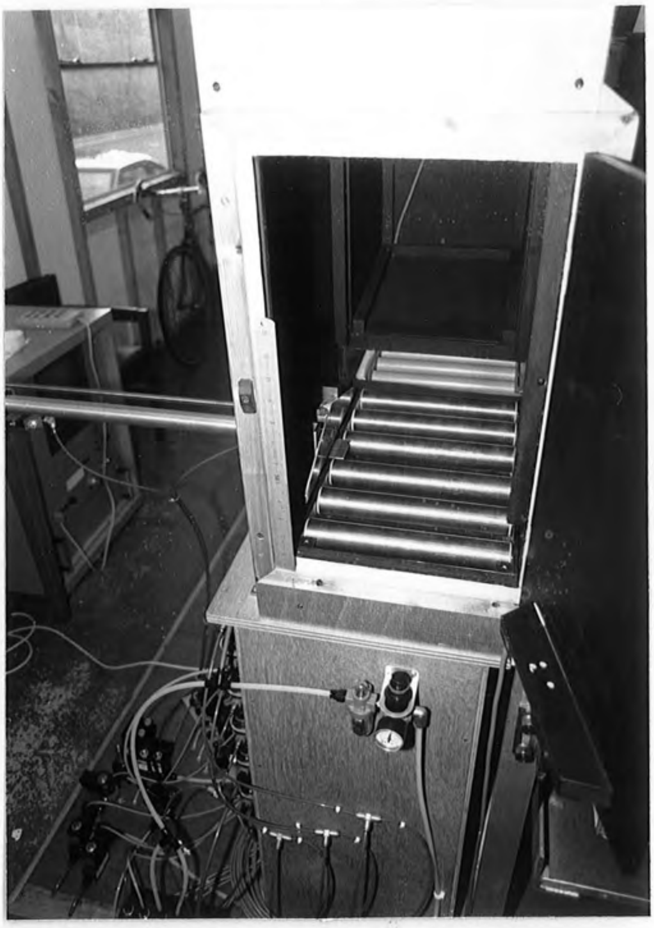

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Photograph 5.

This photograph shows the cup magazine from the north and taken from below the assembly track.

The solenoid bolt brake can be seen on the right of the cartridge base and it can be seen mating with the small vertical pins on the base of the cartridge.

Photograph 6.

Close up of the picking position of the cup magazine taken from the north.

The large sensor on the right by the cassette recorder is the stack sensor, and the two small silver sensors on either side of the magazine at the top is the datum light beam.

Photograph 7.

The centre of this photograph shows the pneumatic cylinder type of brake registering the cutlery cartridge in its magazine.

This photograph was taken from the south of the baseboard, looking down the magazine track.

Photograph 8.

View of the tray magazine taken from the north of the baseboard. It shows the lift cylinders extended to contact the vacuum chucks with the top tray.

The tilt cylinder for the flanged wheel track is visible at the left edge of the picture. It is retracted indicating that the magazine cycle has just reached the point of contacting the tray.

Photograph 9.

This picture shows the same view as Photograph 8. but a moment later when the lift cylinders are retracting, lifting a tray.

The tilt cylinders are extended to swing the wheel tracks out of the way to allow the passage of the tray.

Photograph 10.

The bowl magazine is shown from the south east corner with the blade in its operating position and with three rows of bowls left to be loaded.

The support strut can be seen on the right and the motor and lead screw arrangement can be seen above the aluminium tray.

The conveyor track and boxes behind the bowl magazine are concerned with the stripping of dirty trays which takes no part in the work described.

Photograph 11.

The bowl magazine can be seen with the strut collapsed to allow replacement of the aluminium magazine tray in the frame.

Photograph 12.

This photograph shows the various natural resting aspects of the UHT milk carton when it is dropped onto parallel rails.

The two positions on the far left are those desired.

Photograph 13.

The brush magazine is shown with the collection chute removed to allow the purpose built brushes to be seen. The original, spiral brushes can be seen in the background.

Photograph 14.

A view down the magazine hopper is shown with the brushes in the 'accept' position ready for the entrance of an object.

Photograph 15.

The same view as Photograph 14. but with the brushes in the 'release' position preventing any items except the one within the brush, from leaving the hopper.

Photograph 16.

This view shows the operation of the screw magazine with two different sized objects. It was taken before any of the guides were added to ensure that all the items were dispensed on the left side of the hopper and that only one item could occupy a screw pitch.

Photograph 17.

This picture shows a general view of the prototype equipment taken from the south west corner of the baseboard.

The galley trolley lift with a galley trolley in position can be seen in the foreground.

The tall wooden box seen behind the trolley lift at the lefthand edge of the picture, is the inspection box. The tray transfer is mounted in the bottom of this box.

Photograph 18.

The other side of the galley trolley lift can be seen on the left of centre of this picture.

The hydraulic mast that performs the lifting can be seen and the sprung guide to control the position of the trolley is visible halfway up the lift frame on the left.

The object in the left foreground is the hydraulic power supply for the ram.

Photograph 19.

This is the view from the west side of the baseboard, through the reject door at the side of the inspection box. The transfer can be seen inside with the transfer cylinder visible on the left of the picture.

The microswitch to trigger the operation of the transfer is mounted in the block of wood attached to the bottom of the door (bottom right).

Photograph 20.

This shows the pneumatic cylinder type tray brake and clamp. The lefthand cylinder is extended to stop the tray which rolls from right to left. The cylinder, top right, is then extended to clamp the tray against the flanges of the rollers.

CHAPTER ONE

AUTOMATION

1.1 Introduction

Assembly has traditionally been the preserve of manual techniques. This is not surprising because an operator has a flexibility and adaptability that is very difficult to reproduce in a machine. Until very recently, computing power and sensor technology were not sophisticated enough to give any semblance of these characteristics.

It may not always be desirable or necessary to bestow the assembling workstation with adaptability, as it may be totally dedicated to the assembly of one part or sub-assembly. Adaptability is however desirable to accommodate part variability and manufacturing tolerances.

Machines can be designed to put a peg in a hole for example. Great problems can then occur if the hole moves a fraction away from the intended position or if the peg is slightly oversize. Either could be caused by an in-house manufacturing tolerance variation or by poor quality control by a supplier. Bought in parts will often give these problems because the tendency will be to relax tolerances to reduce costs. The variation can become large if the same part is obtained from several different sources.

Owen [1] suggests that suppliers may pass out-of-tolerance parts because they know that it will not affect the performance of the product. Quite large variations may be possible before the performance of the finished product is affected, but the variation may prevent the successful implementation of automatic assembly.

If it is uneconomic to tighten tolerances, then the assembly machine must be capable of accommodating any differences in parts. In some cases this will involve in-built compliance of the workhead but in other cases, the application of sensor technology may be necessary. This will increase costs dramatically not only because of the cost of hardware but also because of the cost of the development work necessary. Research nowadays is concentrating on vision technology because of applications where a large degree of part variation is encountered. On a simpler level, contact or force/torque sensing will give sufficient information to cover most tolerance variations. Many instances exist where micro-switches, photo-detectors and piezo-electric devices are used to sense the presence of an object.

TI Creda use an automatic system to assemble domestic kettles as described by Townsend [2], not for the benefits of increased productivity but to decrease the damage to the kettles' appearance.The shiny surface that they are trying to protect has caused many problems with sensing because the use of non-contacting photodetectors is not feasible. The surface produces many reflections which confuse the sensors, so non-contacting proximity detectors had to be adopted.

Force or torque sensing is now commonly used in Remote Centre Compliance (RCC) devices on robot wrists. Amongst the many manufactures of these devices, a typical one is produced by INA of Germany and is described by Warnecke and Haaf [3]. The device allows a maximum deflection of eight millimetres along the axis of assembly, enough to cope with the majority of robot position errors. Force sensing is incorporated to provide feedback of the relative alignment between parts up to a force of 3.8 Newtons. In addition it is sensitive to applied lateral forces and applied moments, giving separate indications for all three elements of the insertion condition. The robot can then be programmed to find the point of lowest torque or force which will correspond to the optimum assembly position.

Compliant assembly methods help in the problem of inserting a peg into a hole. If the workstation attempts insertion with lateral displacement between peg and hole, the insertion force will fall outside tolerance so a different position will be tried. If insertion is attempted in the correct position but without the axes coinciding, the leading edge of the pin will contact the far side of the hole. The near edge of the pin will contact the near lip of the hole and any further movement towards insertion will generate a torque that can be sensed and acted upon.

The reason that RCC devices have been used almost exclusively with robots, is because robots have the computational back-up to allow a sensor generated signal to be acted upon. Such requirements are often too great for the logic sequencers used on other workheads, although this position is changing.

Logic controllers originally used cams or hard wired logic to generate signals; nowadays this function is being performed by microprocessors. These are often similar to those used in robots but are simpler because they need not provide position control. Microprocessors can accept directly any TTL signals, make a logical decision and then operate the appropriate outputs.

A passive compliance device is described by Romiti, Belforte and D'Alfio [4]. The device is called SAGA (Self Adaptive Guided Assembler) and was originally designed as a research tool for investigating peg into hole insertion. The final design has the advantage that it can be used as a dedicated stand alone workstation or can be used in the fashion of a RCC device.

In this guise, the SAGA device allows satisfactory insertion of a peg into a hole that is significantly displaced from its intended position. The disadvantage that this ability gives, is in the physical size of the device. The dimensions would become restrictive in many applications.

In the majority of cases, it is not justified or economic to go to these extremes. Very often, assembly problems can be avoided completely at the design stage by considering the 'rules for assembly'. With reference to the peg insertion problem again, a block of compliant material or some machine compliance will cover small errors providing that the parts have been designed to facilitate this. The simple expedient of adding a chamfer to the end of the pin will allow off axis insertion within a greater tolerance. Giving the hole a matching chamfer will increase the success rate even further. A better design would see the hole replaced with a spigot during manufacture which would completely remove the need for an assembly operation.

Assembly is simpler if the finished part is constructed from a series of sub-assemblies. Each of these can then be orientated for easier assembly.

Simplicity is gained if the assembly can be performed in only one direction and in one plane. This can be seen in the assembly of printed circuit boards (PCB) where very high assembly rates have been achieved. Here all the components are inserted from the same direction and on the same plane (the board itself forms the assembly plane).

Kahler and Ahm [5] describe the modifications to a gas valve assembly with these points in mind. The original design had not been performed for automatic assembly, so after four steps had been identified; the reduction in assembly cost was seen to be around seventy per cent.

Hitatchi have developed a quantitative system for reviewing product design which they call "the assemblability evaluation method". Its basic form is outlined by Ohashi, Yano, Matsunaga and Yamada [6] who describe it as a method for designers to judge how simple the assembly of a given part will be. In addition, it provides correlation with assembly costs to find the cheapest and simplest part for automatic assembly.

Bracken and Insolia [7] describe an application where consideration of assembly techniques has allowed robotic assembly of a highly complex product. The product is a printer mechanism and the authors show how the inclusion of non-functional features to the parts allows the retention of a new part whilst the robot applies the fastening mechanism. The system therefore, does not require one robot to clamp the parts together whilst another applies the fixing. Such an assembly technique comes naturally to a human operator since co-ordination between two arms has been developed to a high degree.

1.2 The Early Development Of Automation Hardware

From the initial development of automation, machines have been created to exploit the economies of scale. The first significant application of assembly automation was seen in the automotive industry. Automation had already been established in materials handling and machining but it was in the automobile industry in particular that there was sufficient need to overcome some of the difficulties of assembly. The construction of vehicles involves sufficient scale, resources and perhaps most significantly, a large range of applications. A car is essentially a set of complex sub-assemblies; the engine, gearbox, bodyshell and so on that come together in a final assembly stage. The completion of the sub-assemblies and the final assembly occur at a high frequency and with very little variation.

Automated machining, handling and assembly often result in increased production and invariably a increase in consistency and quality. These benefits are being sought by companies seeking survival, so the interest in these areas is understandably great.

The machinery manufacturers started by developing equipment dedicated to the continuous and rapid production of one part or sub-assembly. These machines took the form of a single workstation, often to perform assembly of only one part to another, both being provided by appropriate feeders. Very high speeds are possible by inserting all the relevant parts into their casing simultaneously. Such assembly could be achieved with either several different machines, appropriately synchronised or with one machine fed with all the parts.

1.3 Flexibility

At this point the concept of flexibility should be introduced. The design lifespan of any part or assembly is finite, so due consideration must be given to the ease of changing a machine from one assembly operation to another. A long lifespan may justify a completely dedicated machine to be scrapped on completion of production of that part. If a minor change is required to that part or the way it is assembled during its lifespan, it may be impossible to accommodate it on a dedicated machine. This leads to the early demise of the equipment in favour of a completely new one, or the abandonment of the change. The flexibility of such a machine is very low. The degree of flexibility required of a machine must be carefully balanced against the expected product lifespan and the increased cost of that flexibility.

Flexibility is a concept that is difficult to quantify and comparisons between two machines performing the same task can be difficult. Del Gaudio and Del Sarto [8] describe an assembly system for motor fans which was intended to possess great flexibility. The line is designed to perform twenty operations on fifteen different styles of motor fan. The authors endeavoured to develop the concept of flexibility to allow comparisons to be made with other systems. The simplest comparison that can be made is the percentage down time whilst the system is set up for the next item. However, the authors point out that the problem with this technique is that it cannot handle the situation where the line is unable to cope with the new part. They then suggest that a separate value analysis approach should be taken for the general purpose machines and for the dedicated units. The bottlenecks can then be identified and corrective action taken. If it is impossible to improve the flexibility of the dedicated units, a measure of the increase in flexibility of the general machines is gained to compensate.

A machine that inserts all the parts simultaneously into an assembly will have very low flexibility. The tooling on the workhead will be very specific to the assembly that it has been designed for and any change will probably be difficult to accommodate.

Alternatively, a single machine per part may well be more expensive initially but will be easier to alter as the change will probably only effect one machine. Development and maintenance costs will be reduced if the separate machines are identical and only the tooling is part specific.

Schwartz [9] identifies the benefits that should be gained from a flexible manufacturing system. The ability to be quickly changed over from one product to another is the most immediate benefit. Along with this ability, minimum work in progress, minimised obsolesence of capital equipment, predictable throughput, maximised yield and reduced assembly costs per part, should be realised.

Instead of simultaneous assembly, serial part insertion could be adopted. This involves separate machines being arranged down a transport device, thus allowing the number of workheads to be as large as necessary. The transport device will take the parts through their assembly sequence and will only yield complete parts after the last machine.

Serial lines normally operate synchronously so that benefits can be gained from a predictable production rate. Synchronous operation is achieved by actuating the workheads by camshaft. Good cam design will then ensure that production at each station is synchronised regardless of line speed.

An asynchronous machine requires a more sophisticated controlling system and the addition of buffers to even out the different production rates of the workstations. The major advantage of operating the system in this fashion is seen when it is necessary to integrate manual stations with the automatic ones. There may be operations that are too complex for a machine to perform, or to perform rapidly enough. Operators compensate for these restrictions.

An operator's production rate will vary and the system controller will be able to accommodate this by control of the buffers. The overall speed of the assembly operation will then be dictated by the rate of the slowest workstation. Production speed can be increased by paralleling the slowest station as far as is necessary to produce an acceptable rate.

More sophisticated assemblies demand that the part should be built upon a pallet type fixture that can be easily transported between numerous workstations. Indeed the pallet may be part of the transfer mechanism or indexing conveyor. Very often, the major part or casing of the assembly is stable enough to be handled without a fixture but where a complex fixture is required, care must be taken that the empty pallets can be returned for refilling. Both a turntable machine and a closed loop arrangement will perform this function automatically.

Providing this is taken into account, the number of loops, buffers and manual stations in a closed loop arrangement can be chosen to suit the assembly and the production regime. Loops can be used as production buffers or assemblies can be directed around them when extra machines are needed.

The more standardised that the workheads are made, the cheaper they become and the easier they are to use. Additionally, a customer needing a system to his own individual requirements will be able to buy the mix of machines that he wants without paying the price for a custom made arrangement. The addition of a custom made or a standard indexing conveyor plus a control unit will give a system which is quickly installed and requires little development. The only remaining work will centre around the part specific tooling required for each machine.

The modern approach of controlling systems with micro-proccessors lends itself well to the control of loops, branches and manual workstations and in particular to asynchronous operation.

Where a 'family' of parts is being assembled with minor differences between assemblies, a separate set of instructions can be held for each pallet. The pallet would have to be identified on approaching each workstation, usually done with bar codes, and only stopped if that operation is required in the build sequence of that assembly.

Completely dedicated systems suit very large batch production because of cheapness, but they possess very little flexibility. The type of modular system just described would suit medium to large batch production.

Walters [10] states some conservative figures for the cost of placement of one item. Although the figures ignore differences in efficiency and multiple shift working, they are a good representation of the relative costs.

METHOD	COST IN PENCE
Manual	3.5 - 0.7
Automatic	0.7
Robotic	
Dedicated	2.0
Flexible	5.0
Very fast flexible	1.3

These figures are only based on the requirements for a particular application in PCB assembly. The author points to the expense of large numbers of parts feeders and an expensive clench unit as being the cause of the high flexibility cost with robots.

Flexibility is increased where the simple and quick replacement of a single workstation is practical. Minor product variations can be catered for in this way and small product mixes can be handled by branched micro-processor based systems. The conversion of one of these lines to a completely different method of assembly requires considerable time and money.

When batch numbers come down to single figures, a truely versatile and adaptable machine is required. Jigs have to be made as versatile as possible or simple and interchangeable. Their operation must be controlled by a sophisticated control system with appropriate sensor back-up. The combination of visual and tactile sensing must allow the controlling software to compare the actual perfromance with that which was intended. The operating environment must be as unstructured as possible for maximum flexibility.

For random parts in random order, the system must recognise the part presented to it and call up the instructions for assembly. The workhead is given the appropriate instructions, it collects the correct parts from their feeders and performs the relevant operations in their assembly. For this purpose, the workhead must be reprogrammable, very flexible and quick in operation. Modern day industrial robots provide all these characteristics and so are used in many assembly system where a significant degree of flexibility is required. Back-up work to assist in robot integration has included the development of more versatile magazines, automatic fixture changing and remote centre compliance devices. All these technologies are aimed at reducing the amount of environmental structuring within these systems and hence increasing flexibility.

1.4 Summary

This chapter has introduced the idea of automation adaptability to accommodate variations in the parts to be assembled. The variations discussed concerned tolerance differences throughout the lifespan of that part and errors in insertion. Consideration of the problem of peg-into-hole assembly highlighted all the various aspects of insertion and indicated the problems that can be encountered when the accuracy of the placing device is significantly less than is needed. Compliance added between the workpiece and the manipulator is seen to remove a large portion of the error. Assembly is then possible even with tight tolerances between the peg and the hole.

It has been shown how sensor feedback on such a compliant device increases the success of tight tolerance assembly. This is only possible however if the manipulator is software driven and has the facility to move the device to the point of minimum force or torque. The combination of sensor feedback and a compliant joint has been called a Remote Centre Compliance Device.

The discussion then traces briefly the origins of automatic assembly from the automotive industry. The logical progression can be seen from the starting point of high volume dedicated machines to adaptable low batch manipulators. The adaptable nature of the latter devices has been called flexibility and is necessary in order to compensate for the finite lifespans of products. Consequently, on product changeover, assembly systems can be re-configured to handle the new part.

The differences between arranging the manipulators in series and in loops were discussed. Reliability, flexibility, cost and accessibility were factors to be compared before either could be considered suitable for any specific application. The discussion concluded that a branched system with software reprogrammable manipulators , robots, would be the optimum solution to fulfill the demands of low batch number and high flexibiltiy. The system must then possess the most unstructured environment possible for the benefits of assembling random parts in random order to be realised.

CHAPTER TWO

PROJECT BACKGROUND

2.1 Project Aim

The aim of the work outlined was the design, construction and testing of an automated assembly system, incorporating a large degree of flexibility to handle a wide range of parts. These parts were the meal trays which were being manually assembled at the British Airways Catering South, Heathrow Airport.

To this end, a comprehensive study was required of the current operation to examine any possible changes. Any adjustment that could assist in the introduction of automation must be examined thoroughly from economic, maintenance and operational viewpoints.

Adjustments may be possible in the equipment itself to make assembly easier and changes may be possible in the current working practices.

2.2 British Airways Catering - Existing System

British Airways Catering Centre South is a factory complex situated within the perimeter of Heathrow Airport. It provides all the meals, bar services and ancillaries for British Airways trans-continental flights. It receives all the dirty equipment from arrival flights, washes the utensils, cooks food for outgoing flights and assembles it onto the trays. The assembly is performed in batches for specific aeroplanes and the schedule of assembly is tied to the flight timetable. Assembly of a particular flight's catering begins several hours before the departure time and once it is complete it is placed into cold store. The average aircraft requires upwards of three hundred individual servings per meal. The longer flights require several meals, snacks and enough bar service to cover demand.

Two classes of passenger are catered for, Club Class and First Class passengers, and the equipment upon which the food is presented varies with the class.

Club Class meals are presented on a plastic tray that has deep indentations to restrain the individual bowls containing the food. There is a bowl containing the hors d'oeuvre,another containing the dessert, a sideplate with a bread roll and a butter pack and a cup with a small carton of milk. The set is completed with a cutlery pack that contains a serviette, a towelette, condiments and stainless steel cutlery, all sealed into a polythene sleeve.

First Class differs in that the tray has no indentations, the crockery is china and silver condiment sets are provided.

At present there is a different tray and equipment combination for virtually every type of aircraft in use. This is due to the variation in the galley layout of the different aircraft. A new design of galley applicable to all aicraft will standardise the situation. The new equipment will be installed in the next year and will give a standard meal tray for each class throughout the fleet. In addition, the galley trolleys used for transportation will be rationalised until only three types remain.

The number of each type of tray will vary with the size of the aircraft, the destination, and with the number of passengers. Exact numbers of meals to be prepared, and the mix of types is gained from ticket information. In addition, menu variations are offered such as salt free, low fat, low cholestrol and Kosher. All preferences are stated on purchase of the ticket and the information is passed on to the Catering Centre. Consequently, the number of meal variations is large and the batch number variable.

The food is prepared in conventional kitchens and then hand assembled into the containers. The main course is handled completely separately as it is the only hot dish to be placed onto the tray. This course arrives on the aircraft separately, it is heated in a fan oven and added to each individual tray before distribution. The food is nevertheless served into the main dish manually at the Catering Centre in the same fashion as the other dishes.

The hors d'oeuvre dish and the dessert dish are the other two containers that require filling before final assembly. The bread roll, butter and milk carton are added at final assembly. The two dishes are stored and transported around the site on flat, open, three sided , aluminium trays. They hold eight rows four across and have special shelved magazine trolleys to transport them.

The empty dishes are laid out in formation on the aluminium trays by hand and then each item of food is placed in turn into the dishes. The hors d'oeuvre typically contains about five separate items whilst the dessert generally has one or two different parts. Each type of dish is assembled until the schedule is filled, then the full magazine trolleys are pushed to the tray assembly area which is remote from the kitchens.

The tray assembly room receives clean, recycled cups and sideplates from the washing line, dishes from the kitchen, bread rolls from the bakery and the other components from stock. The cutlery pack is assembled in-house though the serviette and condiments sachets that are sealed in with the cutlery are bought in. All bread products are obtained from an outside supplier so they are bought in batches and used as appropriate. The type of bread roll changes every day so that any stale rolls from a previous days assembly can be spotted and removed from the current job.

The assembly operation is performed on three conveyor lines. Each line has four operators for assembly and a further one for galley trolley loading operations. The two types of filled dishes are presented to the assembly operators on inclined shelves loaded from the rear. Cups and sideplates arrive in random order in grey plastic tote bins. Trays arrive in stacks. Cutlery packs are stacked in an orderly fashion into plastic bins as they come off the pack assembly line and it is in this manner that they are used by the assembly operators. Rolls are delivered in plastic bags within cardboard boxes, each bag contains several hundred rolls. Milk cartons come in small cardboard boxes containing around one hundred in random order.

The galley trolley loading operator is assisted by a mechanical lift that holds three galley trolleys side by side with their doors open. The galley trolleys can then be raised to any convenient height for loading and the operator must insert three trays per shelf into each. The average time for loading a tray is ten seconds from start to placement in the galley trolley. These trolleys hold thirty three trays so a major delay is encountered every seventeen minutes whilst the trolleys are changed.

Problems sometimes occur if a component runs out. When this happens, all the other specific consumables and the completed galley trolleys are put into cold store until the missing part becomes available again. When storage has been accomplished, assembly of the next task is commenced. As soon as the missing part of the previous job becomes available again, the current task is shelved in favour of the more urgent job. Long delays in the procurement of the missing part will be detrimental to the freshness of the remainder of the food. If scheduled time is exceeded in restocking a missing part, the aircraft will be delayed.

2.3 Project Specifications

The aim of the overall project was to design, construct and test a prototype system to assemble the meal trays automatically and then load them into galley trolleys.

Several initial specifications were laid down:

1. Trolley loading and tray assembly were to be completed within a defined time.
2. The assembly operation must not allow any incomplete trays to be despatched.
3. The reliability of the entire system must be high so that equipment failure would be rare and would not cause a complete loss of production.
4. The process must meet acceptable hygiene standards within the bounds of the budget and the requirement for a prototype system.
5. The system must reduce or eliminate the need for constant operator attendance.

The tray and dishes that the prototype is built around is the Club Class service designed for use on Boeing 747 trans-Atlantic flights. This service was the one that was current at the beginning of the research period and was intended to be the first 'standard' system. The tray has since been modified several times and no standard system will be adopted until the new galley comes into service. The prototype was still designed around this particular tray and since adaptability was a desired property of the final design, its use is still valid. A prototype should be used to develop basic ideas, detail changes will always be necessary when the production system is built.

It is important to consider how the final system would fit into the present situation. When introducing an 'island' of automation into an otherwise totally manual arrangement, care should be taken to ensure complete compatability. The system should be simple to link with existing manual methods without creating extra tasks. In addition, to get the most benefit from the system, British Airways will have to look seriously at automating upstream of this area. They intend to do this but not necessarily in the near future. Therefore, the assembly system must be designed to be as simple as possible to connect with other automation.

2.4 Automation System Choice

The choice of system depends on British Airways' attitude to their assembly practices. The prototype has been designed around the working practices prevailing at the start of the research period. Indeed, it is only after considerable exposure to automation ideas developed in this project that these practices have come under review. It is not now certain whether assembly will continue to be linked with the flight timetable. It is possible that batch production techniques will be adopted, one day's production produced at a time and distributed accordingly. Batch techniques may have a detrimental effect on the quality of the food as it will have to be stored for longer periods before consumption.

Either way, the parts to be assembled are ideal for the application of automation since all assembly is performed from the same side and the tray forms the plane of assembly. The equipment in a given class also effectively forms a 'family' and variation is restricted within that family. Menu variations are presented on the same equipment as the standard food option. Therefore, the assembly system has only to contend with the difference between the two different sets of equipment. The variation in the food will be accommodated by the flexiblity of the magazining system.

A high degree of flexibility is still required of any workstation as the design of the specific components within the sets often change with great rapidity. As new ideas appear or new preferences come through from the cabin staff, the components will change to accommodate them. During the period of this research, the tray design has changed four times for one or other of these reasons.

If batch production techniques are adopted, the serial type of dedicated machine using standard workstations would provide the best solution. The change from one set of components to another would have to be simple enough so that it can be accomplished within a period of the order of half an hour. The increased production rate of this type of dedicated machine will easily cover this delay providing change over is not performed more than twice a day.

At the time that the prototype started its build stage, there was no indication that British Airways would change their assembly practices. The prototype has therefore been designed to produce assemblies in numbers that are generated by ticket sales for specific flights.

The mix of First, Club, special menu and standard menu will vary considerably and will not be known until the closing date for tickets. The variation of assembly tasks and the frequency of the changes indicate a high degree of flexibility. Such a characteristic is only available from a robot. Therefore, the prototype was designed around reprogrammable robots serviced by extremely flexible feeding magazines. Most of the menu variations are handled by the magazines and only the pattern variations are left to the robot.

Maczka [11] points out the pitfalls of isolated islands of automation as doing little to improve product quality or productivity. He states this in the initial stages of an exhaustive analysis for justifying automation which is beyond the scope of the current work. Only British Airways know what their aims and strengths are.

Boothroyd and Dewhurst [12] define a simple, stepwise system for automation justification. Whilst the exact figures for the British Airways application are not known, an analysis based on estimated figures is shown in Appendix 1. The result given indicates that a programmable assembly machine based on programmable workheads such as robots, would provide a simple solution to implement. The solution shows that these workheads should be arranged in a serial fashion rather than in parallel. If the figures used were more accurate, reflecting the greater variation of parts, the solution may have indicated a parallel system or may have indicated a manual system.

2.5 Summary

Chapter two is an in-depth discussion of the way that British Airways arrange their current assembly and what equipment they use. The detailed study revealed a very labour intensive operation. Each assembly operator placed on average, three items onto a tray before the complete tray was loaded into the galley trolley by the last operator. Some idea of the timing required to complete these operations was gained and some of the flow interruptions were identified.

A study of the hardware and the menu revealed the current wide variety of tray sets in use depending on the aircraft type. The equipment was seen to be heading towards a standard set along with the adoption of a standard galley in all aircraft. Furthermore, a large number of menu variations were indicated. The sixty or so menu variations will continue to be offered because of the attraction to the passengers. Further study revealed that the exact combination of these meals for a given flight is decided at the time of ticket sales. The assembly information only reaches the Catering Centre shortly before assembly is due to begin.

The use of programmable robots in the British Airways application was indicated combined with extremely flexible magazines. The robot would accommodate the differences in the equipment between the two classes while the menu variations would be handled by the magazine system.

CHAPTER THREE

ROBOT ARRANGEMENT

It was apparent that the project specifications allow great freedom in the organisation of the equipment. Principally, the robots could be used in either a serial fashion or in a parallel arrangement.

3.1 Serial layout

A serial arrangement would be the closest to the current manual lay-out in that one robot would effectively replace one operator (Figure 1). The two or three items that are currently picked manually at each station would be robotically picked and handled in the same manner. An assembly line of four operators would be replaced by at least four robots but the same assembly speed cannot be expected because of the inability of robots to keep pace with humans, particularly if the operator uses two hands.

Advantage would be gained by synchronising the machines, giving a predictable and steady assembly rate. The manual arrangement does not provide this because the number of stoppages in the present system is high and their occurance is irregular.

A straightforward installation would result if all the current racking is retained. The aluminium trays would also be retained along with their handling system. The disadvantage is that the robot would be picking up items in the same fashion as would a blind-folded operator. It would have to use a repeated search pattern or remember the exact location of the next item to be collected.

Such a serial arrangement would also have the effect of moving the labour saved from assembly to another function. In order to achieve uninterrupted production, the operators would be required to perform magazine loading duties instead of the assembly. Any proposal for the arrangement of a system for this application must avoid a labour shift since reduction in labour costs is one of the major reasons for considering automation.

Perhaps the most significant disadvantage of a serial system is that a complete stop in production will occur upon failure of any of the workstations. The line will not stop initially but it will produce incomplete assemblies during the entire downtime of that station. A tray inspection station would logically be installed to spot this condition and to alert supervisors or to stop the line.

Allowance for such a situation is possible by introducing redundancy in the form of a 'spare' robot in a cell arrangement on the end of the line to perform rectification work. It would be provided with magazines of all components in order to assume the function of any station that has gone down. If more and more of the assembly stations fail, this rectification cell will assemble an increasing proportion of the tray. In the extreme, it would have the capability of sustaining production at a much reduced rate in the event of failure of all the workstations. With the increase in the reliability of industrial robots, a quoted up-time in excess of ninety eight percent is not unusual, failure of all the workstations is unlikely to arise. Therefore, the rectification cell will remain inactive for a large portion of the time. Economic justification for such a back-up system may be difficult so it is unlikely that a serial layout will have this facility. Any failure would then have to be accepted as a consequence, or some provision for manual intervention provided.

A somewhat different arrangement is described by Nonomi and Matsui [13]. Working at Hitatchi, they found advantage in combining a serial system with robot handling for medium batch production of a rotary compressor. The distinguishing feature of this system is that the robots are track mounted and transport the workpiece through its assembly sequence. Advantage is gained in the simplicity of the jigging for the workheads since re-orientation of the parts can be undertaken by the robot while moving from one workhead to another.

Hirabayashi, Hamada, Akaiwa and Kikuchi [14] describe the same equipment and point out the advantage of being able to alter the number of robots. Changes in the production rate can be accommodated by increasing or decreasing the number of robots in the system. The variation in the number of robots carrying parts and loading machines is a simple method of altering the production rate, but the capital that will be tied up in idle machinery however,will prevent the adoption of this arrangement in many applications.

The overall cycle time for these operations is not stated but is presumably rather long otherwise the time lost in transportation would be restrictive. As it is, the speed of travel around the oval track must be high but not so great as to make the quoted accuracy of 12-28 micro metres difficult to attain.

The assembly of the British Airways equipment must be performed at a higher rate than that of the Hitatchi system to be economic. In addition, the accuracy requirement is much lower. A track mounted arrangement of robots could therefore not be justified in this instance.

In the case of British Airways tray assembly, complete production hold-up is unacceptable and the final solution must always be capable of limited production. However, this attribute must not be gained at the expense of redundancy and repair must be as simple as the IBM system where robots can be kept in store.

The system at IBM installs key buttons into computer keyboards and is described by McKillop [15]. The arrangement is a serial one employing a number of robot stations each inserting either one feature button or up to six standard buttons simultaneously. The flexibility requirement is high due to the large number of variations in key patterns. The serial system chosen is justified because the buttons will be the same except for colour and legend. The required flexibility is not in the placement pattern but in the selection of the correct keys.

No redundancy is provided in the line for failure back-up but all the robots are standard units and their tooling is bolted on. Therefore, workstation failure can be quickly rectified by robot replacement.

3.2 Parallel layout

A parallel arrangement is an extension of the idea of a rectification cell to give a complete system of assembly cells. Each cell would be an individual workstation grouped around a common transport mechanism (Figure 2). This conveyor would no longer take the assembly through its construction stages but would simply remove complete assemblies and collect them for trolley loading. The cells would again require a full set of magazines per cell as well as magazines that contain or can be loaded with variations.

Nonomi and Matsui [16] describe a cell arrangement at Hitatchi for the assembly of a differental pressure transmitter. This product has only eleven parts of which there are four types yielding five types of product. The robot in this case is situated in the centre of the cell with its magazines arranged around it radially. The main conveyor is used to index into the cell the major part of the assembly and to index out of the cell with the finished components.

Four basic elements are defined by Williams et al. [17] which may require modification or good design for a flexible cell. They are:

1. The parts feed.

2. The sensors.

3. The end effector.

4. The vice.

They place considerable emphasis on the use of sensors since flexibility in their application is gained from an ingenious approach to component recognition. Specific details of performance are not reported but it is evident that sensing time in such a system would be critical. No part orientation or recognition is proposed in the feeding system, a process that would not involve delaying the robot.

The assembly scheduling can be very flexible because different cells can be assembling different variations simultaneously. If seventy five per cent of British Airways' passengers travel Club Class and eat a standard meal, the same percentage of cells could be set to produce standard meals leaving the remainder to assemble First Class and the other variations. For this degree of flexibility, the number of cells must be chosen carefully to ofset the slower rate of production that is likely from each cell. A logical number of cells for this application would be a multiple of three as the galley trolleys accept three trays per shelf.

In the case of three cells, if one cell were to malfunction, two thirds of normal production could continue. This will allow meal schedules to be filled and delivered to the aircraft allowing a slightly late departure.

Good design of magazines is paramount regardless of the system arrangement. The aspects which are crucial for the successful implementation of automation in this situation are the ease of filling and the ability to adapt to feeding different items.

The most important specification for tray assembly was considered to be very high reliability. A serial system offers less in this respect than a cell system so it was rejected in favour of the latter. The prototype built at The University of Durham is therefore based around a single tray assembly cell and a single trolley loading cell linked by a length of conveyor.

The individual parts of the two cells are shown in Figure 3 and Photographs 1 and 2.

The tray is dispensed by the tray magazine in the north east corner. It rolls down the main assembly conveyor to the assembly position below the robot. The robot picks each item from its respective magazine and assembles it onto the tray. The complete tray is released to roll down the main conveyor into the inspection box in the north west corner of the baseboard. Within this box, it is inspected. If rejected, it is removed through the access door in the west side of the box. If accepted, it is south west corner of the baseboard. The loading is performed by a transfer device in the base of the inspection box.

3.3 Summary

In chapter three, the possible robot arrangements in a complete system were discussed with respect to the ideas developed in chapter two. The first to be studied was a serial arrangement of robots with one robot replacing one operator. It was seen that this would allow the retention of the majority of the equipment presently used but this advantage was heavily outweighed by the disadvantages.

A distinct shift in labour was identified from the assembly of trays to the filling of the magazines. To avoid any change in labour function, it was clear that any system proposal for this application would require better magazine design.

Advantages in a predictable production rate from a synchronised system were weighed against the expected susceptibility to complete failure of the system on failure of one machine. Since a very high dependibility had been identified as a high priority, the concept of a rectification cell was introduced. A robot with a full complement of magazines would be provided at the end of the line to perform rectification operations to any faulty trays identified by the vision inspection system.

Study of reliability figures on a range of industrial robots indicated an average 'up' time of around ninety eight percent. Therefore, it was considered likely that such an extra cell would not be economically viable, thus laying the system open to occasional complete failure. The discussion then proposed that a system made from a number of these rectification cells, each producing a complete tray, would offer reduced production in the event of one machine failing. In addition, extra flexibility was identified as different assemblies could be produced simultaneously on different cells.

It was proposed therefore that the prototype should be built as a cell system, with one tray assembly cell and one trolley loading cell.

CHAPTER FOUR

ROBOT

4.1 Configurations

It is important that the word 'robot' is properly defined because it has been used to describe a wide variety of different machines.

A robot is an easily reprogrammmable device that can perform manipulative tasks. It uses microprocessors to control position, speed and special functions. Such parameters can be changed by altering the data held in the microprocessor. Robots are usually electrically powered as electric motors are simple to control. Larger robots intended for heavy lifting operations are often hydraulically powered to gain the benefits of the better power to weight ratio.

A manipulator is a device to perform manipulative tasks but it is not required to be easily reprogrammable. Manipulators may use a microprocessor but only as a sequencer to move the limbs in the correct order. Position sensing is not necessary because the extension of a limb is controlled by a moveable stop. Reprogramming is accomplished by manual adjustment of the stops, unclamping them and moving them into the new positions. Manipulators are very often pneumatically powered, with the sequencing either by microprocessor or by cams which directly operate valves.

Robots or manipulators can be arranged in different configurations and with differing numbers of degrees of freedom. The most popular is the jointed arm configuration which looks like a human arm. The human arm has evolved into a perfect device for performing the operations that we need, so it is only logical that a robot arm in the same configuration would gain the same benefits. The jointed arm is adaptable to perform many varied functions especially when possessing the same number of degrees of freedom as the human arm. Most robots have only a limited number of degrees of freedom since rigidity is decreased with ~~the~~ their addition.

The cylindrical configuration is common in manipulator construction because two of the main degrees of freedom are linear, something that is simple to achieve with pneumatic cylinders. These degrees of freedom are the motions of moving the arm up and down on a post, and moving the arm in and out from the post horizontally. The third motion that is required is that of rotating the post along its axis, allowing the end of the arm to reach any point within a cylinder.

The motions of the robot can all be linear if the robot is made in the form of a cartesian machine. As its name suggests, the three motions are mutually perpendicular giving an X,Y,Z co-ordinate set. Great accuracy is ususal with this configuration because the quality of manufacture must be high to avoid jamming

The rigidity must also be high for the same reason. In addition, the magnification of errors by revolute joints is not present.

A hybrid of the jointed arm and the cartesian configuration is currently common in the assembly field. It is referred to as a Selective Compliance Assembly Robot Arm (SCARA).

The construction takes the form of an 'L' shaped arm in the plane of the assembly with a Z axis perpendicular to this plane. It gives the advantage that great stiffness is possessed perpendicular to the plane of assembly facilitating insertion. A certain amount of compliance is possible in the robot joints in the plane, to ease the insertion of parts slightly out of position.

Verhaeghen [18] describes a similar arrangement but with significant differences. The machine that he has called SUFAR (Super Fast Assembly Robot) is intended to perform light assembly tasks such as PCB assembly. The author has sought a design that will significantly reduce the inertia experienced whilst keeping the operating envelope large. To this end, his 'lambda' machine has a quoted speed of 160 metres per minute whilst still retaining an accuracy of 0.02 millimetres. The inertia is significantly reduced by the removal of all the operating machinery into the base. The moving members of the robot are then only the Z motion, two stuctural members and a joint.

4.1.1 Revolute or Jointed Arm Machine

The great virtue of these machines is that they can be adapted to perform most jobs, they are the nearest to a universal robot.

Owen [19] points to the similarity with the human arm to explain their popularity in the assembly field. By duplicating the motion of the human limb, their installation is simpler when they replace human operators since most of the existing equipment can be retained. He also notes that the use of rotational joints is often faster than linear movements.

Toepperwein [20] points to the problem of spatial resolution of such joints. Spatial resolution is described as a function of the design of the robot control system and it measures the smallest increment of movement possible by the arm. It is a combination of control resolution and mechanical inaccuracy. A robot working in mutually perpendicular linear axes possesses constant spatial resolution throughout its workspace. A robot that uses rotational axes will produce a tool movement proportional to the extension of the tip from the axis of rotation for any given rotational increment.

A given robot may not be the best machine for the task even though it may be capable of performing the operation. This is true for the application described in this thesis, assembly of the trays.

The robot must be inverted and mounted above the magazines and assembly track due to lack of space and to keep the equipment compact.

The assembly is performed in a vertical direction into a horizontal plane in common with the majority of assembly tasks.

Both of these requirements create difficulty for revolute machines. They are difficult to move in a straight line along the axis of the gripper as this movement requires a complicated selection of the robot's rotary motions.

Worn and Tradt [21] consider that an important requirement for any robot is that the operator should be able to move it in cartesian co-ordinates without taking into account the kinematics of the arm. In addition, they consider it important that the operator can alter the orientation of the tool without changing the spatial co-ordinates of its tip.

For some robots, the operator has no control over the tool trajectory but can only programme points to be visited. Any movement along the gripper's axis is then defined by a series of closely spaced co-ordinate points so that interpolation by the controller will approximate the desired path. The combined delay along such a path may well be unacceptable, if the robot has a small delay between each movement in order to perform position calculations. Some of the more elaborate machines have the ability to move along a gripper's axis as their software is sophisticated enough to perform the co-ordinate transformations in real time. This facility is refered to as movement in tool space. Movement is then along a set of axes as if they were attached to the gripper.

The usual co-ordinate set that is used in programming is a set that originates from the base of the robot. These co-ordinates are referred to as world space co-ordinates.

The robot available for the British Airways assembly task is a Smart Arms 71/750 made by Systems Control. It is a machine designed primarily for research purposes and does not have the facility of tool space movement. It is therefore up to the ingenuity of the programmer to produce the correct co-ordinate sequence to approximate this movement.

An operator drives the robot to the desired point in space by using a key pad, and when satisfied that the position is correct, the co-ordinate set at that point is recorded in memory. On completion of the sequence of positions, the robot moves from one point to another by interpolating the co-ordinates in a way defined by the manufacturer. The programmer has therefore very little control over the actual path taken by the robot. Picking an object out of a magazine in a vertical movement is therefore difficult and slow, due to the complexity of the movement and the number of combinations of different limb motions required.

This was found to be a major obstacle in the successful operation of the British Airways' system, therefore, a vertical pneumatic slide was mounted between the arm and the hand. The robot then sited itself vertically above the magazine or tray and the slide took the gripper vertically down to the picking position. This device greatly simplified programming and increased the speed of operation. Despite it though, the revolute machine possessed an awkwardness of operation that slowed down its cycle, and still required a complex combination of movements from the limbs to perform simple up,across and down sequences.

4.1.2 Cylindrical Machine

A robot was needed that used a co-ordinate set including a vertical axis. Owen [22] describes the ideal assembly robot as one that can move along a vertical axis and service any point in a horizontal plane. A cylindrical co-ordinate machine has these characteristics and so the British Airways' revolute machine was exchanged for a polar co-ordinate robot.

The mounting position of the new robot had to be the same inverted position but the machine now had an axis that was almost parallel with the axes of the magazines. Picking items out of these magazines was now simple, and placing the items onto the tray was also easier.

The disadvantage of this particular machine was the lack of sophistication in the software which made programming it a very difficult and hazardous operation. In addition, the radial reach of this particular robot was insufficient to cover the magazines and the tray. It became necessary to add a further degree of freedom to the arm in the form of an extension that could be rotated in the plane of the tray. For reaching to the extremities of the 'r' (radial) motion, it was swung round to point out along the axis of that motion. For reaching the nearest points, it was aligned back along the axis towards the base.

The speed and reach of the robot were now adequate but the loss of rigidity caused by the installation of the extension and the programming difficulties were unacceptable.

4.1.3 Cartesian Machine

By far the best device to use for this installation would be one using cartesian co-ordinates. Cartesian machines are often used for assembly in a plane such as PCB assembly where great precision is required. Because of the assembly being confined rigidly to one plane, they tend to be built with very little movement in the Z direction and hence are unacceptable in this situation.

The alternative arrangement is to construct the axes onto a horizontal frame encompassing the work envelope. The X carriage runs on the frame with a Y axis running across the X carriage. The Z axis is attached to the saddle of the Y motion and operates through the frame.

The frame type of X,Y,Z robot is not readily available in the small size required for this application, since their use is confined to ultra-high precision assembly, or to large scale palletising. Their manufacture requires a high level of accuracy to prevent the carriages from crabbing or jamming and the positioning of the end effector is very precise. It was hoped however, that a purpose built cartesian machine could be manufactured for this application but the design had to be shelved due to shortage of funds.

4.1.4 Robot Choice

It would appear from the trials that have been performed with these various machines that all types of robot could be used in this installation.

To get the best performance from a revolute machine, a robot must be chosen with sophisticated software and a high operating speed to offset its disadvantages. On the other hand, the adaptability of the machine may justify its choice if there is a possibility that the robot will be used in other applications.

A cylindrical co-ordinate machine would be particularly suitable providing it has the necessary reach to cover the working area. The software possessed by such a robot would have to be better than the machine tested, but it is unlikely that any industrial robot would have an operating system as crude. Some difficulty may be encountered though, in selecting a polar co-ordinate machine of the desired size because they are available only in a restricted size range.

A SCARA machine would undoubtably be fast enough to perform this operation and would possess the necessary sophistication. At present though, a SCARA machine of sufficient size is not available to cover this application. Their use is presently confined to assembly in one plane requiring very small movements in the Z direction. The Z motion necessary in the British Airways' application will be at least the depth of the assembly conveyor plus the depth of a loaded tray plus necessary clearance. This is so because the magazine tracks must exit under the assembly track.

A cartesian machine built onto a frame would be the best solution to the assembly of the trays as high precision and high speed would be possible. The models that are available at the moment tend to be more expensive than other configurations mostly because of the accuracy possible. Very high accuracy is not required in this application since location to within one millimetre is acceptable. A cartesian robot built to give accuracy of this magnitude would not perform very well.

The SUFAR concept is interesting in its possible application in this system. It offers X,Y,Z co-ordinates, high speed, and more than sufficient accuracy. The lifting capacity is of the correct order of magnitude so that the machine would not be over-specified for the task.

Although the machine is not commercially available, such a robot with properly designed guides and actuation, could be successfully employed in this application. It would remain to be seen however, if the software could compute the co-ordinate transformations with sufficient speed to gain full benefit from the quoted specifications.

The prototype assembly system has been constructed around the revolute machine mentioned above. Sufficient funds were not available to purchase the optimum machine but the exact choice does not affect the operation of the remainder of the equipment other than in the speed of operation.

Whatever the configuration of robot selected for production, Schwartz [23] states that simultaneous horizontal and vertical movements should be performed at all possible times.

Referring to a simple pick and place operation, Schwartz [22] points to three successive accelerations and decelerations in a conventional 'gate' movement (three distinct movements, vertical, horizontal and the vertical again). An improvement of twenty percent in cycle time is quoted for an 'arch' movement (two movements with simultaneous vetical and horizontal components) of the same size.

4.2 Gripper

The success of the system depends a great deal on the ability of the robot to pick up the items. In this respect, the design of the gripper is just as important as any other aspect of the system design.

Lundstrom, Glemme and Rooks [24] discuss important aspects that must be considered for a successful gripper design. The load that it must pick is an important parameter and in this case, the maximum load will be around two hundred grammes. With a load so small, the inertia forces generated during robot motion will not be significant. Therefore, the gripping force need not be high.

The most important criteria to consider are the dimensions, orientation and tolerances of the object to be handled. Other criteria which may affect the design are speed of operation and the effects of environmental oil, moisture, temperature and chemicals.

In this application, the speed of gripper operation does not need to be unnecessarily high, one second would be sufficient to give the cycle time needed by British Airways. Environmental effects should not be problematical since the elements that cause them should not be present in a food processing installation.

Owen [25] identifies five clamping methods and four gripper actions. These include parallel action, scissor action, one fixed jaw and sprung open or closed fingers. Parallel action uses the geometry of parallelogram motion to ensure that the jaw faces are always parallel regardless of separation. The scissor action is much simpler being two crossed members with a pivot at the crossing point. Consequently, there is always an angle between the jaw faces when separated.

Of the identified clamping methods, grippers using adhesives are impractical, piercing grippers and magnetic grippers are only useable on the cutlery pack and are also impractical in the British Airways application. Vacuum clamping is severely restictive as a flat, smooth, horizontal plane is required. The suitable planes which could be used for gripping the dishes with vacuum chucks will be covered with food.

The remaining option is a mechanical action by hard fingers or by expansion grippers. The range of sizes to be gripped is just large enough to cause difficulties.

Picking of an item from the sides is facilitated by the item presenting a large, flat profile for the fingers to grip by friction. All of the items on the tray will be filled or will contain some other part, so they cannot be handled in any other way than by the edge. Therefore, any items that present a good lifting surface when stacked, are simple to contend with. All the items do this except the sideplate which presents very little profile when stacked. The use of parallel fingers (Figure 4) therefore will pick-up multiple sideplates unless the accuracy of the magazine and robot are high enough to allow positioning of only the top item in the jaws. It is desireable not to demand a high accuracy for any of the components of the system for reasons of cost, so this condition must be avoided.

Incorporation of non - funtional features to facilitate gripping is not possible with the British Airways equipment since design changes cannot be performed. To offset this the variety of shapes and contours to be gripped in the British Airways application is smaller than in Bracken's example [26] where features of this type have been added. He categorised each part by its shape and then by its gripping feature. Any part that could not be gripped easily had non-funtional features added at the design stage especially for gripping purposes.

4.2.1 Hard Fingers

Most of the initial work with the prototype was performed with a pneumatically operated gripper with aluminium fingers. The width of the fingers was subsequently increased to prevent the tendancy of parts to turn in the jaws. The maximum permissible width of jaw is limited by the size of the access points in the cartridges.

The addition of soft rubber blocks with cross serrations assisted greatly in the picking of the wide variety of shapes involved. However, the gripper showed very low ability to pick misplaced or wrongly orientated items even with the widest possible fingers so an alternative method was sought.

4.2.2 Bag Gripper

The new design used inflatable bags made from bicycle inner tubes, held in a rigid frame (Figure 5). No mechanical movement was now necessary to perform the gripping action, instead compressed air was forced into the inflatable bags. Release was effected by the rapid change of air pressure from positive to negative.

This method has the advantages of simplicity, reliability, and low constructional costs. Lundstrom, Glemme and Rooks [27] mention the gentle handling of this type of gripper due to the large contact area giving a low contact pressure. This aspect is not important in the British Airways application since nofragile parts will be handled by this device.

The inflated bags showed a greater ability to grip awkward shapes and objects which were mis-aligned than the rigid fingered gripper.

One of their disadvantages is the higher wear rate due to environmental aging of polyurethane and polymer rubbers. The aging effect is unavoidable and unpredictable.

Another disadvantage of the bag gripper is its curved contour which would not allow the picking of low-profile objects from a surface. The problem was acute when picking objects from the top of a stack, the tendency was to pick two or more.

Bag grippers are commercially available in many shapes and sizes so it is possible that a commercially available version may overcome the disadvantages of this construction. Frohlich [28] describes gripping and clamping elements available from C. Freudenberg Simrit in Germany. This company has developed a series of grippers and clamping systems based on the inflating bag principle. They prefer elastomer grippers because of their reduced maintenance requirements over mechanically linked movements. The resulting range of grippers includes a set of standard inflatable fingers which can be arranged in any desired arrangement for a given application. Considerable development work with a company such as this may have yielded a design with a much greater success rate than the prototype mentioned above.

The size range of the objects that could be picked successfully with the prototype unit was not large enough to cover all the objects for the tray so either a compromise or an automatic hand changing system was needed.

Automatic hand changing systems are useful when diverse operations are being performed at the same workhead. Operations such as handling and screw insertion would be difficult to achieve with a single end effector. It would require a change of hands. It is sometimes possible to construct a turret gripper containing a number of tools. Either way, the increase in the cycle time may far outweigh any possible benefits and would certainly be unacceptable for tray assembly. The range of parts does not justify changing the hand but a magnet will have to be mounted on the final design of gripper to pick up the ferrous cutlery.

A mechanical fingered device gave good range and better positional control whilst an inflatable bag device gave better adaptability. If the mechanical fingers are used to generate the gripping action, it is not necessary to continually inflate and deflate the bags, which can be constantly inflated.

4.2.3 Compliant Gripper

A compliant gripper has been chosen that uses the principle of mechanical operation and inflated fingernails and has been shown to be very successful (Figure 6 and Photographs 3 and 4).

The mechanical arrangement has been adapted from a parallel action gripper, the hinge points of the links have been moved to alter the geometry. The four bar mechanism causes the fingers to be parallel when the separation is correct for a cup. When the fingers are wide open, they are angled to the centre line of the device so that only the top item will be picked from the sideplate stack.

Activation is achieved with a pneumatic cylinder operating on the outer two links and these two pivots are the only attachment points of the cylinder to the gripper. It is effectively floating and its position is biased towards the centre by two weak springs. Sideways compliance of the fingers is then possible when picking an item that is out of position.

The gripping surfaces of the final design are of soft rubber instead of the inflated blisters that were made for assessment. Constructional difficulties prevent the truly successful manufacture of the blisters and trials were performed with pre-formed inflated bags that are adhered to hard finger pads. Their performance was satisfactory but their construction was not sufficiently strong for the application.

The tray assembly system is unlikely to produce badly orientated parts unless there is a major failure but the accommodation of infrequent errors will improve the success of assembly and may well allow successful assembly when there is an error in part positioning.

Compliance is necessary when the accumulated tolerance of position of the robot and the magazine is so great that a non-compliant gripper would fail to pick up. Such an accumulative tolerance can be considered in the same category as defective parts. Waterbury [29] puts a figure of 2% on the maximum allowable number of defective parts, before the effectiveness of the system comes into doubt.The use of a compliant gripper will increase this percentage of allowable defective parts.

4.3 Summary

Chapter four concentrates on the definition of a robot, the choice of the appropriate machine for this applicaton and the end effector.

The definition of a robot varies widely but is in essence a device that is capable of manipulative tasks and is reprogrammable by software. The ability to position the arm from the input of data requires feedback of position and velocity to allow the computations to be performed by the computer.

Three major configurations of robot were studied and their suitability for this application was discussed. The three classifications were defined as a revolute or jointed arm machine, a cylindrical co-ordinate machine and a cartesian co-ordinate machine. The SCARA and SUFAR concepts were mentioned because of their relative merits but they are hybrids of the major configurations.

The revolute machine was seen to be the popular concept of a universal machine but was shown to have serious shortcomings which made its use in this application difficult. Tool space operation was identified as a co-ordinate transformation enabling the robot to move its gripper in a co-ordinate set generated from the axes of the hand. This motion was proposed as an important consideration and it was seen that the revolute machine available did not have this function. The addition of a small pneumatic slide between the wrist and the hand gave a close approximation but a study of the accuracy and repeatability of this machine showed serious shortcomings.

The cylindrical machine was seen to be configured to perform this particular motion so it was proposed as a better robot in this application than a revolute machine. A study of the operation of the cell with the cylindrical machine in position showed its advantages but the lack of sophistication of this particular test machine prevented firm conclusions being made.

The cartesian machine exhibits the same benefits of co-ordinate axes as the cylindrical arrangement, so its use as an alternative was proposed. The practicalities of its use were discussed and the problems in manufacture were identified. It was seen that the accuracy of build required of the machine had to be high to prevent jamming and the resulting accuracy of positioning and cost were excessive.

The discussion concluded that a cartesian machine was likely to be the ideal device for this application. However, the relatively inaccurate and unsophisticated revolute machine was retained due to budget restrictions and the choice of machine available.

CHAPTER FIVE

MAGAZINES

5.1 Magazine Detail

A magazine for an automated system must fulfill two basic requirements to enhance the automation and not hinder it. Firstly, the magazine must have sufficient storage capacity to maintain a given feed rate without the need for constant operator interference for replenishment. Secondly, it must present the items in the correct attitude for the machine that it serves.

To ease the adoption of automated magazining, Tipping [30] and Owen [31] have defined a set of rules for automated assembly from bulk. These rules are stated here as:

Rule 1. Components should be symmetrical.

Rule2. If they are not, they should have marked polar properties by geometry and/or weight.

Rule 3. Components should have the least number of important axes.

Rule 4. Components which can tangle when in a mass should be avoided.

Rule 5. Consistency of dimensions is important.

Rule 6. Components should be designed for easy manual assembly. It is then more likely to be easy to automate.

Rule 7. The product should have a datum point or face.

Rule 8. The product should have location points.

Rule 9. The product should be designed so that one component can be placed on another.

Rule 10. Never turn the assembly over if it can be avoided.

Rule 11. Never bury important components.

Rule 12. Standardise.

Rule13. Eliminate as many components as possible from the assembly.

Rule 14. Eliminate separate fastening wherever possible.

Tipping [32] also states that "the complex range of probable shapes in an assembly precludes any scientific formula to guide the product designer". This explains why the majority of the work in this area is based upon intuition and trial and error. Most authors advise that the development of such devices be left to the manufacturers of the machines who have vast experience to call upon. Against this, the quantitative method devised at the University of Massachusetts by Boothroyd, Poli and Murch [32] is useful as a guide if not as a complete answer.

Redford, Lo and Killeen [33] performed a study of parts feeders. The study covered:

1. Dedicated feeders.
2. Programmable parts feeders.
3. Dedicated feeders serving more than one robot.
4. Feeders with computer vision.

5. Multi-part feeders with several feeding devices on a common drive unit.

6. Magazine systems.

7. Manual feeding.

The cost of feeding was the primary result of interest and the authors' conclusions were:

1. The rate of decrease of feeding cost is relatively small with increasing batch size once four hundred products in a batch is exceeded.

2. Regardless of the feeding system adopted, feeding parts to a multi-arm robot system will cost five to ten times as much as the feeding of parts to a dedicated assembly machine.

3. The difference in cost between the optimum feeding arrangement and the worst is only of the order of one hundred percent. This ratio will hold only for reasonable batch sizes.

4. A vision system based feeder proved to be the most appropriate for families of products with many unique part types.

5. The multi-part feeder proved to be the most appropriate for families of products with relatively few unique part types.

The economic aspect will always be important in the final choice of feeder but as the study by Redford et al. [33] showed, there will always be a selection of successful feeders available. The economic factor therefore must be weighed against capacity, flexibility and ease of operating before the final choice is made.

5.1.1 Development

As described above, the complexity and cost of any automated assembly system can be kept low by good part design and increasing part similarity. The aim of the design of the magazines on this prototype was that minimal standardisation of components would be needed. The restrictions would be confined to certain dimensions of the tray so that it would travel freely and accurately down the main conveyors. All the magazines would be designed towards accepting any size or shape of object within certain limits.

The prototype assembly system was designed around the 747, Club Class equipment, some of which is stackable. The stacking could be done in an orderly fashion and the resulting stack was stable up to a height far above that required for these magazines. This characteristic was exploited for the magazines of these components but there was some concern that the requirement for them to be stacked would have created another manual operation.

Whenever automation is installed in a new situation, working procedures have to be modified. The most significant of the new procedures required in this case concerned the operators at the end of the container washing tunnel. In the manual system, they sorted out the objects coming out of the tunnel into types and segregated them into containers. The containers were plain plastic tote bins that typically held between one hundred and two hundred parts. No orientation was necessary. The new procedure required them to orientate and then stack them into fixtures suitable for use on the automatic magazines.

Furthermore, any orientating of the objects was seen to be accompanied by an increase in inspection. The present system did not offer any significant inspection until the item was removed from its container to be used in assembly. Even then, the assembly line operators often missed any rejects if they were under pressure to finish a job in a hurry. There was a possibility that a passenger would have found an unacceptable container on his tray which would have been difficult to rectify as the number of meals loaded onto the aircraft left few spares.

The British Airways system would soon become uneconomic if hand loaded magazines were used to feed the assembly robots. Zenger and Dewhurst [34] made this observation because magazines that are part specific use expensive tooling. Furthermore, the labour costs of filling the magazines must be included in the assembly costs. In the British Airways cartridge system, the magazines are very flexible and standardised, it is only the cartridge that is part specific. The time required to perform the extra functions of orientating and stacking is considered minimal and hence not expensive. It is also not restrictive since the operators work at the slow speed of the washing tunnel belt.

Problems are raised when the bowls are used without their lids. The lids prevent damage to the food but in many instances it is undesirable to use them and then the bowls are cling film wrapped as a substitute. The bowls are only stackable with the lids in position although the lids are very flimsy and often their dimensions are out of tolerence. The lids and bowls are manufactured by several different sources and no close tolerance has ever been placed on their design. Consequently, many lids are so slack that they fall off and others are so tight that they are difficult to remove. This situation is unacceptable from both a passenger and an automation point of view. An alternative system is needed to handle the bowls when they are wrapped in cling film since they will continue to be used in both forms.

There is an advantage in retaining the aluminium magazine trays on which the bowls are currently assembled, for use in this system. All the current handling devices for this magazine tray, would then be retained to continue their function of moving the assembled items from the kitchens to the assembly area. Extra automation may be introduced in future into the kitchens to streamline the operations associated with bowl filling and handling. As British Airways have not decided what form this will take, continuing the use of this equipment will reduce the expenditure required for this present automated system.

If items are presented in ordered fashion, the need to programme the robot to undergo a search routine at each pick-up is removed. Most robots have this facility built into their software as standard or a routine of 'search from last successful pick-up position' is provided. The first item will be retrieved very rapidly as it will be found quickly, but the thirtieth visit may not yield a part for a significant time due to the extra distance involved. Furthermore, the need to programme a full co-ordinate set for each location in the magazine will be removed if the next part can be delivered to the same point in space during the robot's cycle time.

The search technique has been adopted by Hitatchi in the manufacture of video tape recorder mechanisms. The system described by Nonomi and Matsui [35] indicates the delivery of trays of parts in stacks to a robot workstation on a serial system. A de-palletiser presents one tray at a time to the robot which then picks one item from each location in turn. There is a limited number of locations per tray and the use of a fast SCARA robot will offset the time variability. No indication is given to the speed of operation of the workstation and it can be assumed that the intended production rate is not great otherwise an arrangement which offered faster production would have been adopted. A larger magazine with many locations would use considerable storage space in the robot controller's memory which could be restrictive in programming. Hitatchi gained advantage however in the simplicity of the magazine since the robot does its own dispensing.

Ohashi, Yano, Matsuaga and Yamada [36] refer to the same installation and point out that the robot's software is flexible enough to calculate the individual pick-up site co-ordinates. The operator need only teach the position of the first corner and input data on the magazine dimensions. This would allow the use of this type of magazine in the British Airways application were it not for the restricted space under the robot, the high production rate demanded and the imprecise location of the bowls in the magazine tray.

The cycle time of the cell in the British Airways' application will be substantially reduced if all the magazine discharge points are arranged to be as close to the tray as possible. The reduction in time is gained by reducing the need for the robot to perform long slew motions.

5.1.2 Cartridge Method - Basic Principles

5.1.2.1 Method of operation

A cartridge type of magazine has been developed to handle and present items that can be stacked in an orderly fashion. It was intended to have maximum flexibility in the ease of change from one part to another and in the range of parts accommodated. Any item that can be stacked in an orderly fashion up to a certain size can have a cartridge manufactured to allow a magazine to dispense it.

The British Airways cartridge system described below operates in a similar way to the one described by Hubacher [37]. The system that he refers to has a slightly different function in using a fixed cartridge frame as a buffer for pallets of components. The frames are then made adjustable to accommodate different pallets.

The cartridge, Photograph 5 and Figure 7(31), is a fixture that allows remote filling and ease of transportation around the

Catering Facility. The cartridge accepts a number of stacked items, supports them vertically and constrains them so that they can only move vertically. It is placed in the magazine which aligns the first stack on the first cartridge with a pick-up position. The robot picks the top object off this stack at this position and places it onto the tray. The magazine must now raise the stack vertically upwards by one item so that the returning robot will find the next item at the same picking position.

The picking position datum is defined by a light beam gate, Figure 8(36) and Photograph 6, across the top of the cartridge, fixed to the magazine. Raising of the stack is accomplished by a pneumatic cylinder, Figure 7(33), that rises through a hole in the base of the cartridge, Figure 7(31).

The magazine itself, comprises a length of gravity roller conveyor, Figure 8(30), with wheels, Figure 7(34), substituted for the rollers at the dispensing point to allow the passage of the cylinder rod. The pneumatic cylinder is mounted under the conveyor track in such a way that the lift plate on the end of its rod is below the rolling height when the cylinder is fully retracted. The light beam sensor and emitter, Figure 8(36), are mounted on supports, Figure 7(37), either side of the track, Figure 8(30), at a height that is just above the top of the cartridge.

The bases of all the cartridges are the same width so that all the magazine tracks can be a standard width also. The cartridges hold multiple stacks to reduce the replenishment frequency. Each stack position is registered in turn by brake pins or blocks at the edge of the cartridge on the stack centre lines, which engage with brake solenoids or cylinders respectively on the magazines (Figure 9). On exhaustion of a stack or if a position on the cartridge is empty, a second optical sensor, Figure 8(36A), is activated. The control system retracts the cylinder so that it is clear of the bottom of the cartridge and the brakes are released momentarily. The cartridge rolls through the magazine until the brake re-engages on the next stack position. This may be the next stack position on the cartridge or it may be the first stack position on the next cartridge. In the latter case, the empty cartridge just released continues down the conveyor to be refilled.

5.1.2.2 Detail considerations

Plastic gravity roller conveyors ideally suit this application since they are strong and cheap as well as possessing the ability to be steam cleaned. The self accumulating characteristic of gravity conveyors means that they require no indexing logic controller or power supply.

Two of the prototype magazines have been built with structural supports, Figure 7(37), up either side of the track. Two others are of a modified design which removed the need for any support under the magazine other than the inherent stiffness of the track. They were designed so that they could be attached to any length of conveyor, even in mid span, by drilling only six holes in the track.

The two original magazines used solenoid bolts as brakes, mating with upstanding pins along the edge of the cartridges. These proved to be troublesome and would get worse with the rough treatment that they would receive from fully loaded cartridges being released from the top of the incline. The problem centred around the bearing required for the pin. It must be strong enough to resist the forces applied to it radially and the large torque through it caused by the large overhang of the pin. If the bearing was made strong enough, the solenoid could not generate sufficient pull to overcome the friction within the bearing caused by this force and torque.

To rectify the poor operation, the later magazines were designed with blocks on the cartridges mating with small pneumatic cylinders (Figure 9 and Photograph 7) at the discharge positions. They acted as shock absorbers to fast moving cartridges and the forces that they were subjected to were much closer to being axial along the brake mechanism.

Three of the magazine/cartridge systems functioned well. These were the magazines that handled the cups, sideplates and the covered dishes. In terms of the rules defined above, these three items satisfy rules 1,5,7,9,10 and 12.

The fourth magazine handled the cutlery. This item was not sufficiently symmetrical, the dimensions were not consistent but they did allow a form of stacking. The pack may be upside down which was only important for handling.

The cutlery pack has several inherent problems that hinder the application of automation in its handling. At present, the pack consists of a set of discrete components sealed into a flexible polythene sleeve. The only rigidity that the pack possesses is due to the condiments sachets within it. The sleeve is wider than the sachets and so the separate knives, fork and spoons can pass through the excess width and finish up on the other side of the sachets. The current method of assembling the cutlery pack results in the cutlery being at random positions in the pack. Consequently, the packs have non uniform shape and construction because uniformity and stiffness are not necessary in the present system.

The packs tend to roll onto their edges and not lie flat for stacking because the polythene sleeve is not rigid enough to prevent it and to retain the cutlery on one side.To remove this tendency, the tolerance of the cartridge in its width would have to be reduced substantially until it was only just wider than the condiment sachets. Excessive friction would then result when aligning which would prevent reliable operation.

Successful magazine dispensing of the cutlery pack would be assisted by assembling the pack with the cutlery always on the same side of the condiments set. The packs could then be loaded into a cartridge with the cutlery uppermost to enable handling with an electromagnet.

There would be a possibility of picking two packs magnetically if a situation were allowed where the cutlery could be on the lower side of the pack in the cartridge. The possibilty would then exist where the second pack could break away and fall into a position to hinder the subsequent operation of the magazine.

The cutlery pack must be more rigid to prevent the rolling tendency already mentioned and the process of its assembly must be improved. British Airways have been investigating alternatives for the current pack not least because this pack wastes a large amount of polythene. Suggestions have been made that the pack could be made in the form of a moulded tray with indentations for the various parts, sealed over the top with foil or cardboard. Incorporated in such a pack could be an indentation for butter hence removing the need for an operation placing a butter pack in the tray assembly. With reference to the rules defined above, this pack would satisfy rules 2,5,7,9,10. The cost of this arrangement would be higher than the current assembly but perhaps more importantly, British Airways would have to start stocking bulk butter. The quality of the pack would be increased by the addition of a napkin folding machine and filling equipment for the condiment sachets. Bulk sugar,salt and pepper would have to be stocked and extra labour taken on. Assessments are continuing in order to find the merits of such an advancement against continuing to buy the packs in.

On occasions in the past, the pack has been restrained with a plastic 'C' clip that is manually placed around the middle of it. Its length is equal to the width of the pack. With such a clip in place, the pack becomes rigid, and it can be handled on the ends of the clip, assuming that they are always placed in the same position on the pack. Their dimensions then become consistent (rule 5) and they possess enough polar properties to ensure that they lie flat (rule 2). The fitment of these clips depends on the current tray design and it is fitted only occasionally because of the extra work in the assembly stage and the increased cost of a part that adds very little value to the pack.

In view of the uncertainty in the design of the cutlery pack, the design of the magazine was taken no further. If the pack finally decided upon is rigid enough to be properly stacked, a cartridge could be quickly constructed and the magazine shown to work. Such a rigid pack may be stiff enough to allow handling with rigid fingered grippers instead of magnetically as a further benefit.

The weight of the cutlery pack is another problem. The magazine actuator must be capable of lifting an entire stack of them (the height of the stack will be dictated by the cartridge) or a single pack, with the same precision of movement. The current design using pneumatic cylinders cannot cope with this variation in weight as the correct pressure to lift one pack will not lift a stack of them. The correct pressure to lift the stack is far too high to ensure accurate positioning with only a few packs left. It is proposed that an electrically driven screw jack actuation be employed for this purpose.

One other major failing of pneumatic actuators is that they suffer badly from static friction. It requires an excessive pressure to start the piston moving within the cylinder. Once moving, the dynamic friction is less, so accurate positioning is very difficult. To overcome this in the prototype, the air supply to raise the cylinders was pulsed. The length of the pulse could be varied until the distance moved by the piston was sufficiently small for accurate positioning once static friction had been overcome. Even so, the amount of static friction varies with a number of parameters such as the oil supply, the temperature and the number of consecutive movements. The adoption of electric screw driven jacks in the production environment is strongly recommended.

5.1.3 Tray Magazine

5.1.3.1 Method of operation

This magazine has been designed around the necessity to pick the top tray off the stack, align it with the conveyor track and release it. The alignment is achieved by releasing the tray onto a conveyor track with flanged wheels. The tracks have a large tolerance over the tray dimensions and guide the tray onto the conveyor which has very close tolerances.

The magazine structure is an oblong, open frame mounted on its end with a plate across the top. Two double acting 750 millimetre stroke pneumatic cylinders, Figure 10(55) and Photographs 8 and 9, are mounted vertically on this plate. They are parallel and separated by the length of a carrier plate, Figure 10(56), attached to the lower ends of the two piston rods. A second plate, Figure 10(57), is suspended loosely below the carrier plate and holds two vacuum chucks, Figure 10(58), one at each end.

The 750 millimetre stroke allows contact between the vacuum chucks and the last tray of the stack on the roller conveyor, Figure 9(53), at full extension. The headroom available in the magazine allows a maximum of fifty trays to be loaded at a time but successful operation is possible with less than this maximum.

The vacuum chucks travel down until contact is sensed with the top of the stack of trays. Sensing of the stack top is performed by a microswitch between the loose plate, Figure 9(57), and the carrier plate, Figure 9(56). The vacuum is then generated and the cylinders retracted to the top of their stroke. At this height, the tray is above the height of the exit conveyor, Figure 9(60), which terminates at the side of the magazine frame. This conveyor is extended into the magazine by the two parallel tracks of flanged wheels, Figure 9(61), spaced apart by the length of the rollers in the exit conveyor and hinged at their ends, Figure 10(62). Thus, when the cylinders lift a tray to the top of their stroke, these tracks can be swung clear, (Figure 11), to allow the tray's passage and then dropped back into position when it is clear. The tray can then be released onto the tracks to roll off onto the exit conveyor to the assembly position. The two tracks are tilted by two small, pneumatic cylinders, Figure 10(64), operating from the air supply used to lift the main cylinders back to the top of their stroke. Perfect synchronisation is then ensured between the two actions.

5.1.3.2 Development

It was originally intended to design the magazine for the dispensing of the trays along the same principles as the cartridge magazines just described. The trays stack in an orderly fashion and since they also interlock into a stable configuration, a cartridge would be unnecessary. The tray satisfies rules 2,5,7,8,9 and 10 as defined above.

Unfortunately, the trays also possess a fault that causes them to bend in two directions and to not lie flat. The effect is not noticeable on a single tray but the accumulative effect of a large number in a stack causes it to lean in two directions. A stack of fifty trays leans by a vertical distance of fifteen millimetres in one direction and ten in the other.

This problem has been raised with British Airways and it is not yet known whether its rectification will be simple or not. If it is possible to correct the errors, then it will have to be decided whether there is any advantage in redesigning this magazine along cartridge principles. Against this must be the fact that the protoype magazine that has been built, functions well, but the tolerances were set wrongly during construction so that only the first forty or so trays can be picked successfully. An improvement to the manufacture will allow the intended number of fifty trays to be dispensed.

5.1.4 Bowl magazine

5.1.4.1 Development

A major design aim was that all the components to be assembled onto the tray should be handled in cartridges, as all the handling equipment could then be standardised on one size. Unfortunately, the bowls cannot always be handled in this way as they are often presented without their lids in place. Whether the lid is used or not depends on the type of food and/or the preference of the cabin staff on the aircraft.

The bowl magazine has been designed to handle the aluminium magazine trays that bowls without lids are assembled on, the same trays that are used for manual loading. The method of handling involves a mechanism for pushing the back row of bowls to cause the front row to leave the tray. The bowls must be collected in a mechanism and propelled to the pick-up point in single file at right angles to the axis of the tray. The latter device must be capable of accumulating the bowls at the pick-up point without the assistance of sensors and a control system to reduce costs and complication.

The aluminium tray unloading mechanism had to be arranged so that replacement of the tray was simple. The system designed allows for this by permitting the bowl propulsion device to be swung up, out of the way. Operation from below the tray would have allowed easier bowl replacement but would have required slots to be machined into every tray in service to allow the drive dogs to pass through (Figures 12 and 13). The advantages of easy access had to be weighed against the disadvantages of turning a simple and cheap tray into a potentially complex and expensive one. It was preferable to avoid the latter case and to design the bowl propulsion device so that it operated above the tray whilst still allowing easy access.

The bowls themselves fulfilled rules 1,5,6,7,10 and 12 as stated above, for handling and assembly.

5.1.4.2 Method of operation

Each aluminium tray is manually inserted into a frame, Figure 14(42), which supports it and surrounds it on its closed sides. The vibratory collection chute into which the bowls are pushed, is mounted across the front of the frame along the open edge of the aluminium tray. The rear tube of the frame has a square cantilever beam, Figure 14(45A) and photographs 10 and 11, hinged to it. This allows the guide and its mechanism to be swung clear for tray changing. It is operated by collapsing the rear strut at the double knuckle joint in its centre. A box bearing slides along the guide to which a transverse blade, Figure 14(46), is attached. The blade is moved along the guide by a motor driven lead screw, Figure 14(45).

In operation, the blade is driven to the back of an empty tray and a full tray is exchanged for it once the blade is swung clear. The mechanism can then be returned to the horizontal position once again and the blade advanced to push the first row of bowls off the end of the tray. Blade movement is triggered when the bowls in the vibratory chute leave the bottom sensor gate unobscured. Blade movement is stopped when the leading edge of the row of bowls entering the chute obscures the top sensor gate. In this fashion, when the last row of bowls has been pushed off the tray, the maximum time available to replace it is seven cycle times of the cell before production is halted. An empty tray is sensed when the blade triggers a microswitch, the blade is retracted and the magazine awaits manual tray replacement. The completion of this task is signalled to the control system by the operator pressing a button.

The vibratory chute, Figure 14(47), is a device to collect the bowls and to accumulate them at the picking point. Two alternative designs were tested before the final solution was adopted. It was initially built as a roller conveyor track (Figures 12 and 13) but proved to be impractical due to the short length of the bowl and its lack of inertia.

It was therefore rebuilt as an air chute. A manifold was constructed underneath the chute to duct compressed air to vertical jets. This was unsatisfactory, because a useable cushion of air could not be generated beneath the bowls. The failure was attributable to the design of the ridges on the base of the bowls. The ridges prevent the bowls from sticking to surfaces when wet. In addition, an air chute would be very weight sensitive and would require constant re-adjustment.

Finally, the chute was mounted on angled flat springs and a motor was attached to the underside of it (Figure 14). An eccentric mass on the motor shaft causes the chute to vibrate in a motion that 'throws' the bowls forward down it in small steps. The motor speed is adjustable to gain resonance and hence optimum performance.

5.1.4.3 Detail Considerations

The blade was originally constructed with pneumatic actuation and the guide mechanisms were intended to be simpler. They used flanged wheels running along the top faces of the magazine frame (Figure 15). In trials, it was quickly established that the cylinders were difficult to control due to the static friction problems already discussed. Consequently, a motor driven option was adopted with great benefit to the successful operation of the magazine.

5.1.5 Flexible Magazine

The remaining British Airways parts to be dispensed were the most awkward and could be grouped together as there were great similarities in the problems associated with each one. The parts themselves were the milk carton, the butter pack and the bread roll.

A flexible magazine is necessary for these items as their size or shape is variable and changes with a relatively high frequency. The feeder must be capable of handling a wide variety of parts or must be adustable quickly and simply to accomodate any changes.

Zenger and Dewhurst [38] concern themselves with automatic handling of parts and they refer to Olivetti's experience with the SIGMA systems. Furthermore, Unimation Inc. [38] came to the same conclusions that inflexible feeding devices cause the main limitations on programmable assembly. Inflexible feeders would certainly be a severe restriction on the adoption of programmable assembly for British Airways as the variation in the products has already been seen to be large.

A complicated sensor based feeder such as that developed by Suzuki and Kohno [39] of Hitatchi would not be suitable on the grounds of cost and operator skills. Their bulk feeders are flexible in that they have no orientating filters but provide parts in random orientation and in single file to the sensor system. The parts arrive at an escapement mechanism to separate them and then the part recognition is effected with a vision set-up. The vision station is provided with a turning unit to change the orientation of the part if it is detected as being incorrect. A very similar arrangement has been devised by Hara, Azuma and Hironaka [40] but on a smaller scale. They have removed some of the complication by restricting the number of parts handled.

A much more realistic flexible feeder for the British Airways application is described by Redford et al. [41]. He bases his design on the the need for a feeder of limited capability not designed to handle every part but only those of a given size.

The next step that he took was to introduce a generalised specification for a limited capability feeder:

1. The equipment will have to be general purpose and cheap especially in the cost of production of part specific tooling.

2. Any changeover of tooling or adjustment should be quick and simple whilst giving enough range to suit the majority of small parts.

3. The machine will have to be compact and capable of feeding at the low rates necessary.

Redford's own device [41] fulfills all the requirements that he set down but because of its vibratory nature, it must be considered along with vibratory bowl feeders in the British Airways application.

The concept of a flexible magazine can be extended as far as necessary. Schweizer and Schmidt [42] describe a complex magazining system developed at the Fraunhofer Institut fur Produktionstechnik und Automatisierung in West Germany. In this case, the magazine handled more than one hundred vastly different parts within a reasonable size bracket. The system relies heavily on vision recognition to identify incoming parts to the host computer and initiating the correct operation from the main robot and the palletisers.

The adoption of such a system for British Airways is undesirable due to the complication and more significantly, the cost of the development of the hardware. It is important that the final solution is simple, easy to maintain and should ideally involve no complicated technology. The current maintenance staff will require some re-training to handle a robot but a sophisticated vision system will require manufacturer servicing, causing increased maintenance costs.

5.1.5.1 Milk Carton

The milk carton is a small plastic container holding an individual portion of UHT milk and it has to be fed into the cup. It is preferable to load it into the cup before it is placed on the tray in order to save time and the two together can be considered as a sub-assembly.

The carton is conical in shape with a foil lid over the larger end. The lid is of a larger diameter than the top of the conical part and has an elongated segment so that the lid in plan view is a pear shape. Consequently, the carton only has one axis of symmetry and is stable in many positions including in the inverted state. It satisfies rule 1 in only one direction and only partly compensates with the polar properties of the lid (rule 2). Rule 5 is not fulfilled in that the carton is continually changing but dimensions are stable for any given carton type.

Miller [43] identifies a check list of feeder application considerations. His first consideration is that of feed rate, which is relatively low at one part per three seconds for this item. Part orientation for the milk carton is not important and the tendency for this part to tangle is very low. The physical condition and cleanliness of the cartons should be good unless a carton becomes punctured when the ensuing dry deposits may affect the dispensing. The hopper should also be clear of foreign matter but the wedging tendency of the carton within a confined track must be considered.

Boothroyd, Poli and Murch [44] have developed the UMASS system to assist in the selection of feeders for specific parts. For the milk carton, the length:diameter ratio of the circular prismatic envelope is calculated as 0.9 in Appendix II. The carton is alpha asymmetric because it has no symmetry around its non-principal axis. If the lift tab of the flange is ignored since it presents minimal problems in feeding, the carton can be considered to be beta symmetric. The UMASS code for this part is then 112 for end to end feeding. Items with codes around this number are indicated to be fed in a bowl feeder and section 2 of the handbook indicates the type of tooling and mechanical filters to be used within the bowl. No specific information is given by the authors under the 112 code but the coding chart indicates simple feeding with few problems.

This is the most convenient method of feeding the cartons as they could be tipped in bulk into the vibratory bowl feeder. They would then be presented to an escapement mechanism in the same orientation and in single file.

One of the restrictions to the use of this type of feeder in this application is that the size and weight of the carton is changed at an unusually high frequency. Each bowl feeder must be patiently set up by trial and error until the desired feeding is achieved. The flights inside the bowl must be adjusted to tip any item of incorrect orientation back into the bowl and only allow correctly orientated ones to pass. The size and shape of the carton will dictate the way that these flights are set up. The bowl will have to removed and sent back to the manufacturer for re-adjustment if there are any alterations to the characteristics of the carton. The same operation will be necessary if an operator takes it upon himself to try adjustment.

Smith [45] points to this problem but suggests that the adoption of removable hardware within the bowl will allow handling of similar parts. He also states that it is often possible to change the bowls in a matter of minutes. This will facilitate the change of parts on an infrequent basis.

Bowl feeders are designed to feed parts at very high speed, at a much higher speed than is required in this case. To offset this speed, an accumulation buffer would be required between the bowl and the escapement so that the bowl could be shut off when the buffer was full. It would restart on emptying of the buffer. Two sensors would have to be mounted on the buffer to sense when it is full and when it is empty. A control system would then switch the various components where appropriate.

Smith [45] points to the effect of the load in the bowl on its performance. He states that overloading can slow down the driving unit by sheer mass and that overcrowding leads to more difficulty in parts separation. In addition, the attitude of the parts on the feed track may suffer. Extra capacity would be available from an auxiliary hopper operated from a level control in the bowl.

All these restrictions are mentioned by Zenger and Dewhurst [46] and they add the further restriction of cost of their use in batch production. The cost aspect is important at the initial purchase stage and also in the resetting or replacement of the bowl on a change of part to be fed. It is particularly important in an application such as the British Airways situation where the changes would be frequent to accommodate the continual change in the parts handled.

A feeder that cannot cope with variations in the dimensions of the carton even if they are small is not flexible enough for this application. Some type of flexible feeder is required that can accommodate minor variations in the part that it is feeding.

Vibration may affect the quality of the milk inside the carton so feeders using vibratory transport techniques cannot be used in the British Airways' application.

Yoshida [47] describes a non-vibratory bowl feeder that avoids this type of possible damage to the milk cartons and so may be applicable for the British Airways' application. The feeding is performed by contra-rotating the sides and the base of the bowl and using gravity and lack of centripetal force to do the separating. The tooling and the flights are the same statistical devices used on the vibratory bowl feeder with the same characteristic inflexibility. Therefore, it must be considered as inflexible as the vibratory device, although it offers gentler handling of the cartons.

The milk cartons arrive in cardboard boxes containing around one hundred in random order. If they were loaded into boxes at the dairy in neat rows with a cardboard dividing sheets, the box could have been treated as a cartridge for a magazine similar to the one used for the cups (Figure 16). For this purpose, the bottom would be removed from the boxes and the rows pushed up until they cleared the top of the box. The cartons would then be in a defined orientation and they would then have to be separated into an ordered line. From this position, an escapement mechanism would release a single carton at a time into a chute leading to the top cup of the cup magazine before it was picked. It is unfortunate that the cartons are packed into their boxes in such a random order since they must be manufactured and filled in an ordered fashion. The order must be lost at the very end of their line and they have no reason to pack the cartons in any other way form of tipping bulk cartons into a hopper. This reduces the time and effort that an operator has to expend refilling the magazine and allows it to hold a large number to increase the time between replenishments.

A device that fulfills most of the requirements for the British Airways system is that described by Zenger and Dewhurst [48]. It is a belt feeder which does not have many of the disadvantages of the vibratory bowl feeder and does not cause adverse effects to the parts. It is however difficult to visualise such a device holding the quantities considered necessary for this application without the overall size of the device becoming restrictive.

The feeding of parts when they are very small, in other words a free flowing powder, from a hopper is simple. There is either a trap door in the base of the hopper or an Archimedean screw runs through the bottom of it. For a powder, neither of these methods presents a problem but with an object like the milk carton there are certain objections. The principal problem is that the cartons are relatively fragile. If they break open by being trapped between trap doors or between a screw and its exit hole, milk is then spilt in the magazine. Apart from the objection that this particular carton may find its way onto an accepted tray, any milk in the hopper will go rancid in a short period of time. Subsequent cartons may become coated in this milk which will be very off-putting to any passenger who receives one.

5.1.5.2 Solutions Proposed

The first stage in the development of this magazine concerned a hopper with a trap door mechanism that acted as an escapement and did not damage the parts. The trap doors took the form of long cylindrical brushes along the bottom of the hopper (Figure 18), geared together so as to contra-rotate at the same speed. If a carton got caught in the bristles, they merely deformed around it without causing any damage.

The first model of this device (Figure 19 and 20 and Photographs 13,14 and 15) was constructed using the only cylindrical brushes that were available. These had short bristles in a spiral form along the length with gaps between the rows. The bristles themselves fulfilled all the requirements, they supported the cartons in the hopper when they blocked the exit and they deformed around the cartons without causing damage. The spiral form that they were in prevented correct escapement operation but the device worked sufficiently to justify the technique. Operation of the brushes in an oscillating fashion caused cartons to fall out of the hopper and into a collection chute. Since the brushes were the full length of the bottom of the hopper, the desired individual loading was not achieved as often up to five cartons were dispensed in one oscillations. At other times, no cartons would be dispensed until the bristles had orientated one so that it would pass through.

If any more than one carton is dropped from the hopper at every operation, an exterior escapement will be necessary at the chute dispatch point. The escapement would take the form of a simple turnstile wheel or a more complicated device such as that used by Suzuki and Kohno [52]. Extra control and expense will be required with either method. The control requirement is substantially reduced if the magazine is operated until a sensor across the chute detects the passing of a carton. The magazine must therefore ensure the dispensing of only one carton at a time.

Most of the short-comings of the first prototype magazine derived from the unsuitability of the brushes. The criteria for the optimum brush were now known and a new set of brushes could be fabricated. The length of the bristles is only important in that they should provide sufficient impediment to the bulk of the items in the hopper when the brushes are at the bottom of their oscillation. If they are too long, the arc of the oscillation becomes too great. Furthermore, the space between the rows of bristles must be of sufficient size to allow one carton to enter regardless of its orientation.

The length of the new brushes was equal to the length of one carton to ensure that only one carton was delivered at a time. However, this had the effect of aggravating a problem that was evident in the first design. If the angle of the sides of the hopper are too steep, the cartons frequently jam together in the neck of the hopper and form a 'bridge' that supports the remaining items. When this has happened, no amount of oscillation of the brushes will relieve the bottle neck, especially if the bridge occurs out of the reach of the bristles. Increasing the angle of the hopper in both directions to form a square exit to the hopper, increases the possibility of bridging.

Opening up the angle of the hopper decreases the pressure on the bottom cartons to go into the escapement and hence the magazine stops to function. There will be an optimum angle somewhere between the two extremes but for absolutely reliable operation, some form of vibratory 'jigger' will be necessary.

Ideally, the magazine should have a wide, open hopper and should not require the assistance of vibration because of its possible detrimental effect on the milk. For these reasons, the dispensing of the cartons from the base of the hopper was considered to be impractical.

Further investigations were centered around the Archimedian screw type device. Normally, a screw would be placed into the bottom of a hopper and would propel the items through a hole in its end. The hole would be the same diameter as the outside diameter of the screw and only those items within the pitch of the screw would be dispensed. Any item that was only partially within the pitch of the screw would experience a shearing motion between the edge of the hole and the outside edge of the screw. This would be unacceptable when the item being dispensed was such as a milk carton. Consequently, for any situation where this may occur, the outside rim of the screw was made from bristles.

For complete protection from damage, the length of the bristles would have to exceed the dimensions of the carton. There would be then a strong possibility of dispensing two items simultaneously which is also unacceptable. The only satisfactory way that this could be avoided would be to remove the hole, i.e. the end of the hopper. There would now be nothing to prevent all the cartons leaving together.

The problem of keeping the majority of items within the hopper can be solved by tilting the whole magazine so that the dispensing end is uppermost. The angle must be chosen in order that any item not in the screw will fall back and those items in the screw will be retained.

The device (Figure 21 and Photograph 16) takes the form of a hopper of wide angle, with the screw running up the angle in the bottom. A guide is required to ensure that all the items stay on one side of the screw, in other words, on one face of the hopper. A guide is also required to knock back any cartons protruding from the pitches as they will be a second carton in the same pitch. It is the interaction of these guides and the screw that dictates the continued use of bristles on the outer edge of the screw.

Not every pitch will collect a carton but the control system need only keep the screw turning until a carton is sensed in the exit chute. The magazine has a full cycle of the cell in order to achieve the loading of one carton and this it should be able to do with ease.

The control of the cartons on exit of this device was still difficult as there was always a tendency for them to cross onto the wrong side of the hopper. If this occured and the carton engaged into a screw pitch, there was a much greater possibility of releasing two cartons into the exit chute.

The biggest problem was the selection of the screw pitch. Control of cartons outside the screw was a task requiring persistence in trials with flights and mechanical filters but it was essential to manufacture the screw correctly from the initial design. A screw with adjustable pitch would have been easier to set during commissioning, and would have operated with a wide variety of different parts.

To vary the pitch of a screw, it would need to be manufactured as a spring since the position of each of the coils when viewed along the outside diameter, parallel to the axis, must vary as an arithmetic progression. To double the pitch size, the first coil must extend by one pitch from its current position. The second coil must move two pitches from its original position. The third coil must move by three pitches, the next, four and so on.

This relationship is held automatically when a spring is stretched from both ends. It is then very difficult to allow for the reduction in its diameter, to allow for the extra twist in the spring and to clamp the individual coils. The latter is important to prevent multiple cartons entering a pitch by deflecting the coils defining it.

It was impractical therefore to base the operation of this magazine on a screw and so the concept was changed to that of an elevating hopper feeder as described by Ward [49]. The principle is similar in that discrete pockets are used to catch a single object from bulk and to transport it out of the hopper. This type of device uses a chain for this purpose where the pockets are the spaces within the links (Figure 22 and 23). To vary the size of these pockets along the axis, another chain of the same pitch is caused to travel at the same speed, just below the first.

The outer chain is driven around a six spoke sprocket whilst the inner chain travels around a four spoke sprocket. Consequently, the vertical height of the chains from the sprocket centre line will vary according to the positions of the respective sprockets. The separation of the two chains in the bottom of the hopper will vary continuously during operation imparting a low frequency agitation to the parts in the hopper.

The compartment size is varied by altering the phase angle between the two chains. The range of sizes that can be accommodated is therefore from the full link length to half the link length. The width of the compartment can be adjusted by closing in the sides of the hopper above the chain without altering their angle.

Warnecke and Schraft [50] describe this type of device as a chain magazine and they quantify some of its characteristics. The authors describe its functions as those of storage of workpieces in a given orientation and transfer of orientated or dis-orientated parts.

The workpiece types that are identified as not being suitable for this type of magazine are parts which tangle and long parts. Flat, cylindrical, prismatic, conical, pyramidal, headed, hollow and spherical parts are all considered suitable.

The authors describe a typical chain magazine as designed for a particular workpiece but they consider that such a magazine can usually be adapted to different workpiece sizes within limits.

The shift of emphasis from a feeder that can handle any object within a given range to a feeder that allows flexibility through manual adjustment is reflected by Zenger and Dewhurst [51]. They reduced the complexity of their belt feeder already mentioned, by removing the relatively sophisticated sensor system and adding manual adjustment. Resetting of the resulting machine takes a matter of seconds, providing that the new settings are known.

Orientation of the milk carton is important for aesthetic reasons. This is unfortunate since it is extremely difficult to achieve. For part orientation purposes, it is desirable to know what the probability is that the part will rest in the required way when dropped onto a surface. Boothroyd, Poli and Murch [52] refer to this as the natural resting aspect of a part and they have quantified it empirically. A different figure can be found for a hard or a soft surface as appropriate when following their analysis. For a 95% confidence interval to plus or minus 5%, the authors state that the part must be tossed four hundred times onto the surface or if a bowl feeder is used, fifty parts must be fed ten times to give the same accuracy.

Using this analysis on the milk carton, the probability of landing on the small end is given as 0.02, on the side, 0.78 and on the top face 0.2 .

The large flange on the top of the carton should allow orientation if the carton is dropped onto parallel rails. In fact, there are four main positions that the carton will rest on those rails, only one of which is the correct orientation (Photograph 12). In addition to these four positions, the spacing required of the rails is sufficient to allow a carton to pass through. This rules out the first method for orientating cone shaped items as described by Chironis [53].

Chironis [53] suggests either using contra-rotating guide rods or using a recess and tumbling mechanism. Both devices however, are hindered by the flange on the larger diameter of this carton. Floating the cartons in a water chute to allow the buoyancy to orientate them results in a similar three positions.

In effect, it is not that important which way up the carton is placed in the cup since any orientation may be lost in transporting and handling the complete trays.

The chain magazine has therefore been installed on the British Airways prototype rig to dispense milk cartons in any orientation. The control of the magazine is by one sensor in the delivery chute to sense the passing of a carton and the hopper has been constructed to hold about one hundred items.

5.1.5.3 Butter Pack

Several of the difficult handling characteristics of the milk carton are also possessed by the butter pack, so the solution to its dispensing follows similar lines to those developed for the milk. The major difference is in the shape. The butter pack is rectangular in shape where the depth is considerably smaller than any other dimension. Other than that, the butter pack is constructed and filled in the same way as the milk carton and it is of equivalent proportions to the milk carton.

It will not be affected by vibration to the same extent but the pack has changed with almost the same frequency as the milk carton. Thus rule 5, consistency of dimensions, is only satisfied for a given pack size. According to the rules defined in section 5.1, the pack satisfies rules 1,2,7,9 and 10.

In the UMASS system, the butter pack has a length:width ratio which is less than three and an length:depth ratio less than four (Appendix II) indicating a code of 832 for this prismatic envelope. The coding system shows moderate difficulties in feeding this shape and indicates again the use of a bowl feeder.

The magazine design for this item has been approached in the same way that the previous one has. Indeed, the chain magazine has great potential in the range and size of objects that it can handle. The range will certainly include the butter pack. The relatively small depth of the pack may cause problems within the screw or chain as the pitch will have been chosen to accept a butter pack end on. There is therefore a strong possibility of two butter packs entering the same pitch and fitting well enough that the guide at the top does not dislodge one of them. However, it is possible that the pitch can be chosen to exclude packs from entering long edge first. This may reduce the tendency for duplication within the pitches.

Orientation of the butter pack is slightly more important in this instance in that the pack must be placed the correct way up for aesthetic reasons. Subsequent bad handling is unlikely to disturb this position.

In the UMASS system, the natural resting aspect for the butter pack on the large face is 0.9, on the next largest, 0.08 and on the small face, 0.02 . This analysis takes no account of the flange on the top face which reduces the possibility of the pack resting on anything but the top or the bottom. There is a much higher probability of this item landing on its top face so re-assessing the natural resting aspect using the analysis for headed parts is more meaningful. The new figures are, 0.6 for the correct way up and 0.4 for upside down situation. No amount of analysis in this fashion can cope with the eccentricity of mass caused by the non-uniform distribution of butter within the container. Even if the pack were filled uniformly initially, during subsequent storage the butter may flow leading to a major movement of the centre of gravity.

5.1.5.4 Bread Roll

A selection of locally available bread rolls were taken and their handling characteristics were analysed by the UMASS system. Of the seven rolls, six were roughly spherical in shape whilst the seventh was a finger roll. The six round rolls produced length to diameter ratios in the range 0.25 to 0.71 (Appendix II). The UMASS code for all six rolls was 021 which indicated vibratory bowl feeding techniques with feeding efficiencies between 23% and 52%. Each bowl feeder would be specific to a given roll and so the flexibility in their adoption would be insufficient.

The finger roll gave a length to diameter ratio of 2.9 and an UMASS code of 200. The feeding systems indicated for this code are a reciprocating tube hopper feeder (efficiency 40%), a centrifugal hopper feeder (efficiency 55%) and a stationary hopper feeder (efficiency 27%). The latter in particular will be damaging to the rolls and none of the feeders will possess the flexibility to handle spherical rolls.

Certain rolls currently being used are flow wrapped into individual polythene sleeves. An extension of this technique, if economic, to all the roll types would ensure separation after baking. All problems with crumbs would be removed and the freshness of the bread would be improved. A magazine such as Figure 24 could be adopted if the sleeve were delivered uncut. The escapement would index the sleeve forward to be cut when required. Since this will not be economic at this time, another method must be used.

The bread rolls are bigger than either the milk or butter packs but their dispensing can be handled in the same way. The width of the chain must be made bigger to accommodate the larger size but the near spherical type of roll is ideally suited to fitting into the pitches.

The orientation is again important in that the roll must be placed onto the sideplate before it is picked out of the magazine, the correct way up. This sub-assembly must be placed onto the tray with a butter pack and a roll in place , both the correct way up. The time available to perform this will again be the cycle time of the cell.

Added complication is experienced because the near spherical rolls are often changed for finger rolls and so the size discrepancy can be quite significant. In addition, the rolls are often not separated from their neighbours when they come off the bakery tray. Rolls may arrive connected to others in numbers up to four. Automation to separate them may be expensive to devise so some re-organisation of bakery and buying practices are essential to the smooth running of this system.

5.2 Summary

Chapter five is concerned with the magazining aspect of the project work. This is an area that has already been identified as an important one for the system to function well.

Study of other authors' work led to a set of rules and guide lines being applied to each of the applications. The indicated preferred method was seen to be inappropriate in this situation but this was to be expected from guidelines of such a general nature.

A magazine design was proposed for handling stackable parts in such a way that only the cartridge fixture was part specific. Consequently, very little standardisation was indicated and this magazine was found to be suitable for the sideplate, the covered dish , the cup and possibly the cutlery pack. The latter is not suitable in its present state and discussion as to its failings gave proposals on its alteration in order to facilitate its automatic handling.

After discussion and investigation into a moulding fault on the tray, it was proposed that the tray could not be handled in a cartridge fashion but only by picking the top one off a stack. The tray would then be released onto an alignment fixture before arriving at the assembly point. Using this principle, a design was proposed using vacuum chucks to pick the tray.

A situation was identified where the covered dishes were required without their lids and in this situation it was seen that the bowls were no longer stackable. Therefore, a different type of magazine was proposed which utilised the current in-house transportation trays thus allowing bowl filling to continue in its present form.

The concept of a truly flexible magazine for small, discrete components was next to be studied with regard to the dispensing of the milk carton, the butter pack and the bread roll. Much work by other authors was studied and the relevance of their work to this application discussed. It was seen clearly that their work relied heavily on the use of computer vision recognition systems, an unnecessary complication and expense in this instance. The requirement is for a device that is extremely simple yet can handle infrequent changes in the dimensions of the part within reasonable limits.

The milk carton was seen to possess an awkward shape and unhelpful resting characteristics. It was also considered somewhat fragile with a relatively low feed rate requirement. Consequently, the preferred feeding device of a vibratory bowl feeder was rejected and the use of a non-vibratory bowl feeder was studied. The discussion of the advantages and disadvantages of this device and the proposed designs that followed led to the proposal of a novel hopper feeder incorporating rapid size adjustment to accommodate differing parts. This device was also considered suitable for the butter pack and the bread roll since the problems associated with these items were similar. In particular, a study of the various types of bread roll locally available showed a wide variation of length/diameter ratios, each easily handled but not by the same machine.

CHAPTER SIX

CELL TWO

6.1 Main Conveyor

The prototype has been constructed as two distinct cells (Figure 28). The first cell was devoted to the assembly of trays, while the function of the second was the loading of trolleys.

These two cells were joined by a length of conveyor which may be either a belt, an indexing or a gravity roller conveyor. In the production version, the conveyor must link together three or four assembly cells and deliver all the complete trays to the trolley loader. It was preferable that the conveyor should not need a complex control system and yet should have an accumulating function. It should be strong and light, and satisfy all hygiene requirements without high cost. A gravity system was therefore indicated as the only control requirement was for a sensor at each assembly cell to verify whether the conveyor was already occupied at the loading point.

In the prototype, a length of plastic gravity roller conveyor was used and forms an extension to the exit conveyor of the tray magazine. In a production version, the exit conveyor would have a brake mechanism to catch the empty trays and to define the loading position. The prototype has a solenoid operated device that functions well but is noisy in operation.

An alternative design has been tried with great success. It used a small pneumatic cylinder at 45 degrees to the axis of the track and in the same plane (Figure 29 and Photograph 20). When extended, it contacted the tray corner which was also at that angle. Accurate clamping against the flanges of the rollers was ensured by the addition of another cylinder to contact the top corner of the tray. The position of the tray was thus accurately defined and did not change during loading. When the cylinders were retracted, they were clear of the tray as it rolled forward down the slope. Their action was quieter and much more reliable than the solenoid device already mentioned.

6.2 Trolley Lift

6.2.1 Development

Initially, the trolley loading cell was designed to hold a trolley stationary, to raise completed trays to align with the shelves and then push them in. As the tray was pushed in, it would connect with any trays already present and push them deeper into the trolley. Three trays would be loaded into a given shelf before the control system would start on the next. By arranging the loading system in this fashion, it was considered that benefits would be gained in the high speed and low inertia of the device. Additionally, because the tray is being raised and not the trolley, the size of the device would be significantly smaller. A high speed and accurate lift using stepper motor driven lead screws was designed (Figure 30 and 31) and priced. the resulting estimate was considered to be far too high and the design was considered to be over-engineered for the accuracy of placing required. The accuracy of manufacture had to be set high in order that the slides would work smoothly and not jam. The overall placing accuracy would have been of the order of 0.15 millimetres either way instead of the required 1.5 millimetres. Similar and cheaper designs were considered (Figures 32, 33, 34, 35, 36 and 37) but they all suffered from several inherent disadvantages. Firstly, the length of the vertical travel required, around one metre, indicated this high level of manufacturing tolerance to ensure satisfactory movement. Furthermore, this type of device must visit each shelf three times. At the extremes of its movement, the speed required of it would be prohibitive in order to perform the loading in the available time.

6.2.2 Trolley lift final design

The requirement is therefore for a device that can lift a trolley of maximum weight and that can align the shelves to the rolling height of the transfer unit to within 1.5 millimetres each way. If the loading position is outside the tolerance, then as the tray is pushed in, it will ride over or under any previously loaded trays on that shelf. This effect can be virtually eliminated if the cylinder is operated in three stages. It pushes each tray into the trolley as far as necessary to allow the next tray to be correctly positioned. The effect of any misalignment between the trolley and the loading height is reduced to the possibility of disturbing the positions of the items on the tray as it leaves the transfer. The result is no different to that caused by bad handling of the full trolley between the Catering Centre and the aircraft.

The device used on the University of Durham prototype is a single hydraulic mast lift seen on Figure 28 and Photographs 17 and 18, that functions in a similar manner to a fork lift truck. The platform has four guide wheels, two per side, that run up the inside of vertical channels to provide the guiding and load bearing. The cylinder is mounted vertically with its base on the lift structure. It has a broad pulley at its top end over which a broad chain is passed. One end of the chain is attached to the lift structure near the bottom mounting of the cylinder and the other end is attached to the platform. The movement of the cylinder is hence geared up by a factor of two.

The lift was provided by British Airways and was formerly a manually controlled lift on the end of one of the existing manual production lines. In its former installation, it lifted three trolleys to allow easy insertion of trays into the shelves by an operator. It was cut down to one third of its size and its 'hand' was changed before it was incorporated into the prototype equipment.

Furthermore, it was necessary to tilt the entire lift over at three degrees to the vertical to align the lift axis to that of the transfer.This is the same angle that the conveyors are mounted from the horizontal to provide movement under gravity. In normal conveying terms, this may be considered excessive but the tightness of the tolerances between the roller flanges and the tray can lead to greater than normal rolling friction.

The single cylinder and the poor guides possessed by the lift cause unacceptable rocking of the platform which can affect the loading height without movement of the cylinder. Alterations to the guides have removed most of the play and rolling guides have been added (Figure 38) to control the position of the trolley as it is raised and lowered. Both modifications improved the success rate of loading trays into trolleys. Most of the remaining errors are corrected by the shelf sensing system which operates on the shelf to be loaded and senses the end of that shelf nearest to the transfer.

6.3 Transfer Unit

The loading/transfer unit was built into the bottom of the inspection box so that if a tray was accepted, it could be pushed off at right angles to the axis of the main conveyor into the trolley standing on the lift. It consisted of a short length of roller conveyor comparable in size to a tray but with its rollers made from stainless steel for higher wear resistance. A bracket on the side of the transfer supported a 450 millimeter stroke pneumatic cylinder perpendicular to the transfer and along the trolley centre line. The operation of this cylinder performed the trolley loading. The prototype inspection box that surrounded the transfer, had an inspection door across the end of the transfer to act as a tray stop. A production system would have this replaced by an automatic gate so that a reject tray could continue down an extension conveyor to be rectified.

Problems sometimes arose in the operation of the transfer due to the single cylinder that had been used on the prototype. If a tray to be loaded arrived the wrong way around with the cutlery pack on the upstream side of the tray, it tended to swivel and jam in the opening on loading. The adoption of a larger surface on the cylinder end has removed this fault to allow a high success rate in trolley loading.

6.4 Control System

The sequential control of a production version of this prototype would be performed by a microprocessor based programmable logic controller (PLC). This could be bought off the shelf and be plugged into all the sensors, motors and valves. Unfortunately, one of these devices was more expensive than could be justified for the prototype so a cheaper method was needed. This took the form of a personal computer that possessed the ability to have the number of input and output ports (I/O) expanded. The limited number of ports was expanded with the addition of extra peripheral interface adaptors (PIA) so that sixty four I/O lines could be handled.

The numerous position sensing requirements were handled either by miniature microswitches or by optical sensors. Both types of sensor switched fifteen volts DC which was reduced to five volts TTL by voltage dividers. The signal could then be read directly by the Commodore VIC20 micro computer. The reprogramming ability of such a system gave great flexibility in the way that the hardware was operated.

Similar flexibility was afforded by the construction of boxes of relays to convert the five volts TTL output into mains voltage. Any output line could switch the motors, the vacuum chucks or any of the pneumatic valves controlling the air supply to the cylinders. The pneumatic circuit is shown in Figure 25. Figure 26 shows the flow diagram of the programme for the cartridge magazines. Figure 27 shows the flow diagram of the programme for the complete system.

The mains supply to the computer required protection against spikes caused by the switching of the air compressor and other heavy equipment. The prime source of these spikes was the contactor in the motor for the trolley lift. The fact that this motor used three phase power made protection especially difficult. In addition, all the wires to and from the equipment were carefully segregated to prevent cross talk.

6.5 Summary

Chapter six concentrated on the second cell where the trolley was loaded with complete trays from the assembly cell. The problems discussed covered all aspects of devices to push trays into the trolley at each successive shelf.

The first proposals held the trolley stationary and moved the tray. This arrangement was subsequently rejected due to the speed necessary to put all thirty three trays into the trolley in reasonable time. Combined with this were the constructional difficulties associated with this type of device.

The final proposal moved the trolley to align its shelves with the transfer unit, hence only moving the two parts of the system relatively, on completion of a shelf. The distances to be traversed were more reasonable being constant and only one shelf pitch.

A simple sensor was proposed to align the shelf of the trolley and to provide other vital information to the control system.

The transfer was to be a simple device to allow the removal of rejects and to perform the trolley loading. A system was proposed operating at right angles to the axis of the conveyor so that rejects could be allowed to continue down the incline. Accepted trays would be pushed into the trolley shelf by a simple pneumatic cylinder.

The control system based around a cheap home computer, is described. The advantage of using such a computer is stated as possessing great adaptability at low cost. The alternative of using a PLC device was rejected due to its initial high cost.

CHAPTER SEVEN

CONCLUSIONS AND

RECOMMENDATIONS

7.1 Conclusions

For the project taken as a whole, the aim of designing, constructing and testing a system for tray assembly and trolley loading was fulfilled within the alloted time and budget. The budget restrictions explain the apparently low reliability of the equipment but since it was intended to be a prototype, this is acceptable. The system was never intended to operate in a production environment so a success rate of eighty percent is a reasonable figure and allows demonstration of the basic ideas upon which this system is based. In particular, it was used to introduce ideas of automation to British Airways and to show that a robot system could operate in such a novel environment.

The flexibility aspect has been thoroughly investigated with the software reprogrammable robot covering tray layout variations. Menu variations are handled by the quick change function of the magazines and hardware changes are accommodated by a cheap fixture change. Dimensional differences of discrete parts such as the bread roll, will be adequately handled by the so called 'flexible magazine'. Larger variations will require simple adjustments of this magazine but the downtime for this operation will be minimal.

From the outset, it was clear that the successful implementation of this system depended on the magazining and not on the robot. Although several robot configurations were tried, all types could perform the task but the configurations that were indicated as unsuitable would need more sophistication before being considered.

The magazines have all been built and tested showing the soundness of the ideas on which they function and it is a question of their build quality and specification that will decide their success in production.

7.2 Recommendations

It was intended that this system would be simple and cost effective. What is lacking in its specification is any form of error recovery. Very little sensor information is available about the state of the object gripped or whether it has even been gripped. The addition of several cheap sensors to back up the vision inspection system in this fashion, would allow the spotting of potential or actual failures much more quickly. Beyond this, an error recovery regime could be added with relative ease. Then, on detection of a fault, the robot could try a number of different routines until success is achieved. This would reduce the requirement for operator attendance at very little extra expense whilst making the system more cost effective.

The cartridges for the prototype system were manufactured out of aluminium. In a production version, they should be made in a stonger material or re-designed to be more robust, lighter and capable of holding a much larger number of items. Ideally, a light and strong plastic cartridge should be used that can hold a comparable number of items to the containers currently being used. Any new design could incorporate multiple stacks across the cartridge as well as along its length to give it a restricted number of parallel pick-up points per magazine. The alterations to the existing magazines would be restricted to the addition of multiple actuators to lift the multiple stacks when needed. Facilities could be incorpoated into the design of these cartridges to allow proper nesting when empty. If a standard height were adopted for the cartridges, all magazines would accept all cartridges, regardless of contents, to give extra flexibility.

Now that the bowl magazine has been proved in prototype form, the same principle could be applied in the production version coupled to an aluminium tray magazine. Such a device could easily take the same form as the galley trolley loading lift described and use the existing magazine trolleys that transport the trays. The current magazine trolleys will probably be too non-uniform and too bent to use initially but better designs will alleviate the problems.

The operation of the bowl magazine requires a better quality aluminium magazine tray since the present ones can cause failure to occur. The soft aluminium material from which the trays are made allows the open edge of the tray to become easily damaged. After use, the trays are washed and then stood on the open edge to drain and it is this action that damages the edge. They must be made from stainless steel so that they can handle the rough treatment or the current working practices must be improved. Improvement in the design of the drying racks and sympathetic handling by the operators will give a temporary solution but the long term adoption of better trays must be considered.

In a production version of this system, the adoption of a scissor lift would remove most of the inaccuracy in the prototype lift since it is far more controllable in its movement. In addition, a production version should have the facility to change trolleys when full, without any manual intervention.

The majority of these points would normally be covered under a redesign for production and the problems only exist in the prototype due to budget restrictions causing the equipment to be under specified.

7.1.1 Complete Production Layout

The complete installation must meet specific requirements. The principal of these is that the rate of production of complete trays must equal or better the current manual assembly rate. This implies a loading frequency of less than fifteen seconds.

Ease of operation is increased if all the magazines for the cells are supplied from centralised hoppers and if access to them is good without extravagant use of floor space. The central hoppers should contain enough parts for several hours of uninterrupted production.

One arrangement would place the hoppers centrally and group the cells around them in a circular fashion (Figure 39). The assembly conveyor would circle the equipment and the trolley loading would be performed at its end.

Material flow will be difficult where the magazine tracks come together in the centre of the system. A central turntable would be required to connect the tracks to four master tracks where all the loading can be performed. Operation would then be difficult and expensive to implement and control. Any re-arrangement within the cells to make this possible causes the size of the cell to increase and hence the reach requirement of the robot increases also.

The following are the main dis-advantages of this prototype layout:

1. The radius of the main feed conveyor cannot be too small or problems will arise with trays falling off or being mis-aligned.
2. Loading of new trays cannot be performed at the beginning of the conveyor since much time would be lost in waiting for the first tray to arrive in position.
3. The control system would have to be sophisticated enough to

allow the appropriate number of trays to pass each cell before stopping one for its own assembly task.

4. A separate tray magazine is indicated for each cell.

5. Time would still be lost in waiting for the completed trays to clear the assembly positions since replacement would not be possible until the tray from the cell furthest from the trolley loader had passed.

6. As the radius of the conveyor gets larger, the delays encountered in this way increase. The radius of the envisaged system is around three metres and the delay expected would be around two minutes.

To surmount these disadvantages, it is proposed that an in-line cell system be adopted (Figure 40). The overall size of such a system would be around 5.3x2.7 metres for similar magazines. There is the facility in such an arrangement for the expansion of the magazine tracks in width without making the system unacceptably large. This system has three cells since the trolley accepts three trays per shelf and no great advantage would be gained from the use of more cells. This is in contrast to the circular system which benefits from any increase in the number of cells. With only three cells, shelf indexing of the trolley can be performed during the period that the accumulation track is refilled.

Three empty trays would be sent down the outer track by the tray magazine and they would be caught by the brake/transfer device at the assembly positions. Transfer between the two tracks would then be accomplished so that each assembly position on the inner track had an empty tray. During the robots' cycle time, the next three trays could be lined up on the outer track ready for the transfer on completion of the cycle. At this point, the three complete trays would be released into the accumulation conveyor, the new trays would be transfered and the cycle restarted. During this cycle, the inspection system would have to inspect the trays in turn and either load them into the trolley or reject them.

If a tray loading frequency of fifteen seconds is required, then the cycle time for the robot cells will be forty five seconds minus a margin of approximately ten seconds for the trays to roll into the accumulation conveyor. This gives the inspection system just under twelve seconds per tray to inspect,decide and perform the loading. If the target time of twenty seconds for the cycle time is realised, then the tray loading frequency will be about ten seconds.

With such an arrangement of equipment, it is not possible to arrange the magazine tracks so that they can be loaded from one point without considerable complication in the design. Therefore, easy access to the loading points is essential and a large capacity of those magazines is desireable. Both reqiurements are easily achieved in this arrangement. Magazines for small items may be fed from a common central hopper but separate magazines for all the cells may be considered advantageous. This will prevent total systems failure from the mal-function of one of these magazines.

For a change in menu, or equipment, a manual override could be incorporated to release all the brakes in the magazine tracks. All the cartridges of unwanted items would be rapidly removed from the system and an equally rapid replenishment with the new items would be possible.

Before British Airways decide on the exact specifications of the system that they require, they will have to decide whether to opt for batch production or to continue with the current procedures. If the latter is the case, the assembly of these trays can be performed much more quickly and more cheaply with dedicated machinery. The continuation of current practices will require the flexibility offered by a system such as this. In either case, full benefit will not be realised until receptacle filling is streamlined or automated.

REFERENCES

1. Owen, A.E. Designing for automated assembly
Engineering June 1983 pp.436-441

2. Townsend, P. Automated cell improves quality of kettles
Production Engineer Dec. 1984 pp.9-10

3. Warnecke, H.J. and Haaf, D.
Components for programmable assembly- Grippers, sensors, conveying systems for an industrial robot engaged together with fixed automation.
Proceedings of the 2nd International Conference on assembly automation (ICAA) Brighton 1981 pp.225-233 International Fluidic Services Publications, (IFS), Bedford UK.

4. Romiti, A. Belforte, G. and D'Alfio, N.
Precise assembly by low precision machines.
Programmable Assembly
ed. byW. B. Heginbotham, IFS Pubs, Bedford UK. pp.217-229

5. Kahler, S. and Ahm, T.
Design for assembly- a case study
Proceedings of the 5th ICAA Paris 1984
pp269-276 IFS Publications, Bedford UK.

6. Ohashi, Toshijiro. Yano, Tekeshi. Matsunaga, Makoto and Yamada, Asaji.
The automatic assembly line for VTR mechanisms.
Proceedings of the 4th ICAA Tokyo 1983
pp. 350-361 IFS Publications, Bedford UK.

7. Bracken, F. L. and Insolia, G. E.
Data processing equipment for automated assembly.
Progammable Assembly ed. by W.B. Heginbotham
IFS Pubs, Bedford UK. 1984 pp. 105-126

8. Del Gaudio, I. and Del Sarto, S.
Motor fan flexible automatic manufacturing system.
Proceedings of the 4th ICAA Tokyo 1983
IFS Pubs, Bedford UK. pp.362-374

9. Schwartz, Walter. H.
Robots called to assembly.
Assembly Engineering Vol 28 No 8
Aug. 1985 pp. 20-23

10. Walters, P. E.
Robots in the assembly of electronic products.
Proceedings of the 6th ICAA Birmingham
1985, IFS Pubs, Bedford UK. pp.321-340

11. Maczka, Walter J.

Planning for automated assembly: the common denominators.

Assembly Engineering Vol 28 No. 2

Feb. 1985 pp.16--20

12. Boothroyd, G. and Dewhurst, P.

Design for assembly; A designer's handbook

University of Massachusetts Amherst USA 1983

13. Nonomi, Tatsuva and Matsui, Takeshi

Applications of robots to assembly lines.

Hitatchi Review Vol 32 No. 5 1983

pp. 229-232

14. Hirabayashi, H. Hamada, T. Akaiwa, M. and Kikuchi, K.

Travelling assembly robot.

Proceedure of the 13th International Symposium on Industrial Robots 1983

pp. 20-(19-31)

15. McKillop, A. J.

Robotic keybutton insertion.

Proceedings of the 6th ICAA Birmingham

1985, IFS Pubs, Bedford UK. pp.267-275

16. Nonomi, Tatsuva and Matsui, Takeshi

Applications of robots to assembly lines.

Hitatchi Review Vol 32 No. 5 1983

pp. 232-233

17. Williams, A. M. Walters, P. E. Ashton, M. and Roay, D. S.

A flexible assembly cell.

Proceedings of the 6th ICAA Birmingham

1985, IFS Pubs, Bedford UK. pp. 57-66

18. Verheaghen, J.

SUFAR- A super fast assembly robot.

Proceedings of the 5th ICAA Paris

1984, IFS Pubs, Bedford UK. pp. 95-104

19. Owen, A. E.

Assembly with robots.

Kogan Page, London 1985

20. Toepperwein, L. L.

Robotics applications for industry- a

practical guide.

Noyes Data Corporation 1983

21. Worn, Dr. Ing. H. and Tradt, Ing. (FH) H. R.

Proceedings of the 3rd ICAA Stuttgart

1982, IFS Pubs, Bedford UK. pp. 525-545

22. Owen, A. E.

Assembly with robots.

Kogan Page, London 1985

23. Schwartz, Walter H.

Robots called to assembly.

Assembly Engineering Vol 28 No. 8

Aug 1985 pp.20-23

24. Lundstrom, G. Glemme, B. and Rooks, B. W.

Industrial robots-- Gripper Review

IFS Pubs, Bedford UK. 1977

25. Owen, A. E.

Assembly with robots.

Kogan Page, London 1985

26. Bracken, F. L.

Parts classification and gripper design for automatic handling and assembly.

Proceedings of the 5th ICAA Paris 1984

IFS Pubs, Bedford UK. pp.181-189

27. Lundstrom, G. Glemme, B. and Rooks, B. W.

Industrial robots- Gripper Review.

IFS Pubs, Bedford UK. 1977

28. Frohlich, W.

Grippers and clamping elements- modular elements for the automation of production technology.

The Industrial Robot Vol. 6 part 4

1979 pp. 195-199

29. Waterbury, Robert

Designing parts for automated assembly.

Assembly Engineering Vol. 28 No. 2

Feb 1985 pp. 24-28

30. Tipping, William Victor

An introduction to mechanical assembly.

Buisness Books, London 1969

31. Owen, A. E.

designing for automated assembly.

Engineering June 1983 pp. 436-441

32. Boothroyd, G. Poli, C. R. and Murch, L. E.

Handbook of feeding and orientating techniques for small parts.

Dept. of Mechanical Engineering, University of Massachusetts Amherst USA 1976

33. Redford, A. H. Lo, E. K. and Killeen, P. J.

Parts presentation to multi arm assembly robots.

CIRP Annals Vol 32 No. 1 Harrogate 1983 pp. 399-403

34. Zenger, D. and Dewhurst, P.

Automatic handling of parts for robot assembly.

Annals of CIRP Vol. 33 No. 1 1984 pp 279-281

35. Nonomi, T. and Matsui, T.

Applications of robots to assembly lines.

Hitatchi Review Vol.32 No. 5 1983 pp. 229-232

36. Ohashi, T. Yano, T. Matsunaga, M. and Yamada, A.

The automatic assembly line for VTR mechanisms.

Proceedings of the 4th ICAA Tokyo 1983 pp. 350-361 IFS Pubs, Bedford UK.

37. Hubacher, U.

How to achieve high efficiency in assembly systems.

Proceedings of the 5th ICAA Paris 1984 pp. 161-168 IFS Pubs, Bedford UK.

38. Zenger, D. and Dewhurst, P.

Automatic handling of parts for robot assembly.

Annals of CIRP Vol 33 No. 1 1984 pp 279--281

39. Suzuki, T. and Kohno, M.

The flexible parts feeder which helps a robot assemble automatically.

Assembly Automation Feb 1981 pp. 81-92

40. Hara, S. Azuma, K. and Hironaka, K.

Development of a flexible parts feeding system.

Programmable Assembly ed. by W.B. Heginbotham IFS Pubs, Bedford UK. 1984 pp. 281-288

41. Redford, A. H.

General purpose assembly - the way ahead.

Proceedings of the 6th ICAA Birmingham 1986 IFS Pubs, Bedford UK. pp. 277-289

42. Schwiezer, M. and Schmidt, I.

Computer controlled magazining system

Programmable Assembly ed. by W.B. Heginbotham IFS Pubs, Bedford UK. 1984 pp. 233-246

43. Miller, M. T.

Mechanised feeding of small parts in production equipment.
Automation June 1965 pp. 74-79

44. Boothroyd, G. Poli, C. R. and Murch, L. E.

Handbook of feeding and orientating techniques for small parts.
Dept. of Mechanical Engineering, University of Massachusetts Amherst 1976

45. Smith, F. E.

Applying vibratory bowl- type feeders.
Automation Nov 1962 pp. 97-102
Dec 1962 pp. 79-85

46. Zenger, D. and Dewhurst, P.

Automatic handling of parts for robot assembly.
Annals of CIRP Vol 33 No.1 1984
pp 279-281

47. Yoshida, Ryoichi

On the revolving parts feeder with velocity servomechanism.
Proceedings of the 4th ICAA Stuttgart 1983
IFS Pubs, Bedford UK. pp. 209-218

48. Zenger, D. and Dewhurst, P.

Automatic handling of parts for robot assembly.

Annals of the CIRP Vol. 33 No. 1 1984

pp 279-281

49. Ward, P. W.

Parts feeding for automated assembly.

Proceedings of the 2nd ICAA Brighton 1981

pp. 167-173 IFS Pubs, Bedford UK.

50. Warnecke, H. J. and Schraft, R. D.

Industrial Robots- application experience

IFS Pubs, Bedford UK. 1982

51. Zenger, D. and Dewhurst, P.

Automatic handling of parts for robot assembly.

Annals of CIRP Vol 33 No. 1 1984

pp 279-281

52. Boothroyd, G. Poli, C. R. and Murch, L. E.

Handbook of feeding and orientating techniques for small parts.

Dept. of Mechanical Engineering, University of Massachusetts Amherst 1976

53. Chironis, Nicholas P.

Your latest group of mechanisms to sort, feed or weigh.

Product Engineering Jan 1966 pp. 40-43

APPENDIX I

AUTOMATION SYSTEM CHOICE

The following is the calculation as set out by Boothroyd and Dewhurst [12] to assess the suitability of various types of automation system. The terms listed are those used by the authors and the values are figures or estimates of figures appropriate to the the British Airways application.

Terms

SH is the number of shifts

QE is the capital equivalent of one assembly worker

WA is the annual cost of employing one assembly worker

NA is the number of parts in the assembly

NT is the total number of parts available for building different product styles

VS is the annual production volume per shift in millions

ND is the number of parts whose design is changed during the first three years necessitating a new feeder and workhead

RI is the investment factor

Values

SH=2

QE=54,000

WA=15,000

NA=9

NT=18

VS=3.65

ND>0.5NA

Investment Factor

Investment factor is defined by the equation

RI=(SHxQE)/WA

=(2x54,000)/15,000

=7.2

Using the chart developed by Boothroyd and Dewhurst [12], the suggested system falls into Row 7, column 4. This suggests a system based on a programmable machine in a serial arrangement.

The difficulty level indicated in the development of such a system is given as moderate.

APPENDIX II

ENVELOPE CALCULATIONS

In the UMASS system [44] for feeder selection, the shape of the part must be reduced to the smallest prismatic envelope possible. All protrusions must be ignored and the length:diameter ratio calculated for the envelope.

The major dimensions of the parts mentioned in the text are shown below along with the significant ratios of the envelopes.

ENVELOPE DIMENSIONS

Milk carton — length 32 mm

diameter35 mm

length:diameter ratio is 0.91

Butter pack — length 34 mm

width 32 mm

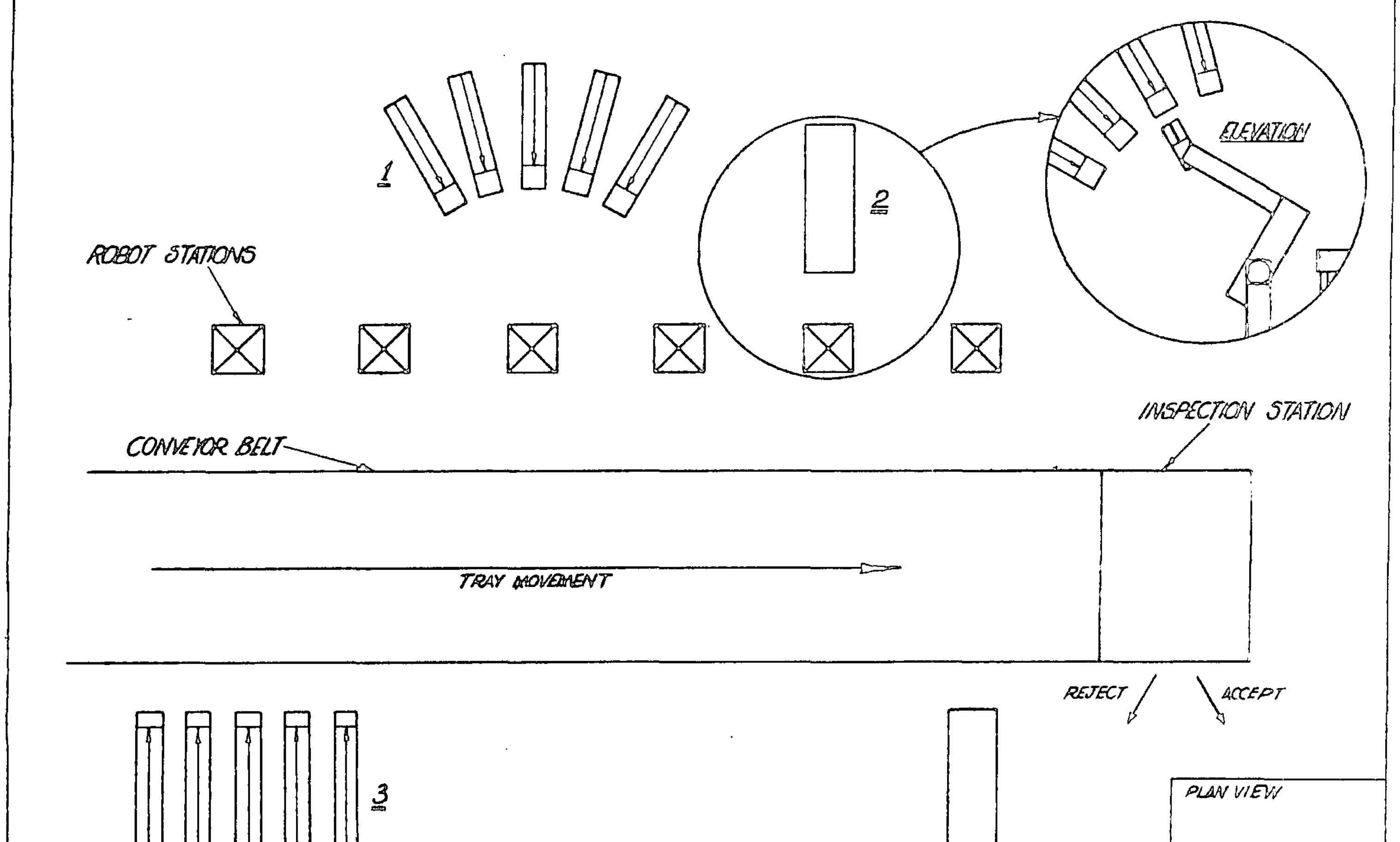
depth 15 mm

length:width ratio 1.0625

length:depth ratio 2.27

Bread rolls	height	diameter	H:D ratio
roll 1	45 mm	75 mm	0.6
roll 2	50 mm	85 mm	0.59
roll 3	60 mm	85 mm	0.71
roll 4	53 mm	80 mm	0.66
roll 5	60 mm	100 mm	0.6

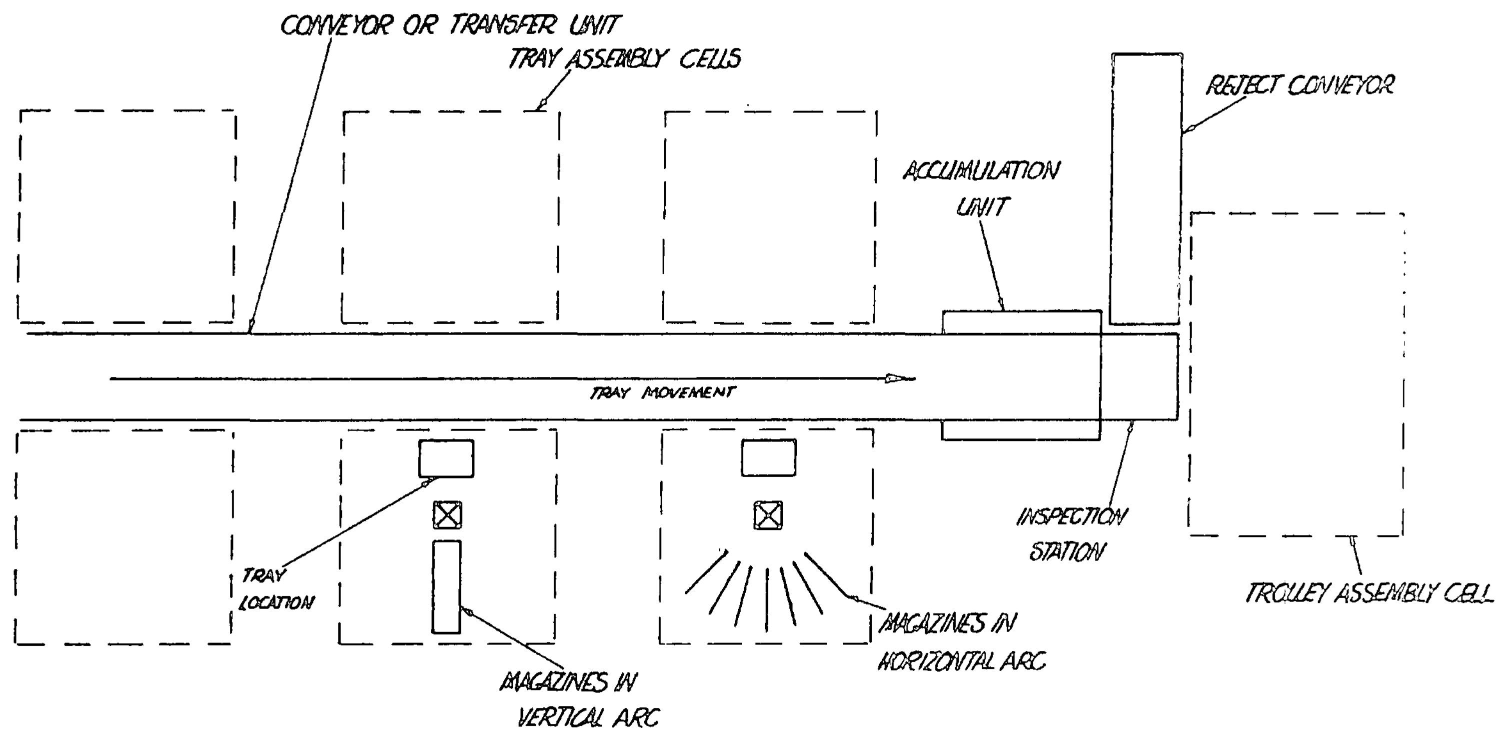
roll 6	30 mm	120 mm	0.25
roll 7	145 mm	50 mm	2.9



IN-LINE (SERIAL) LAYOUT
SHOWING 3 ALTERNATIVE
MAGAZINE ARRANGEMENTS

PLAN VIEW

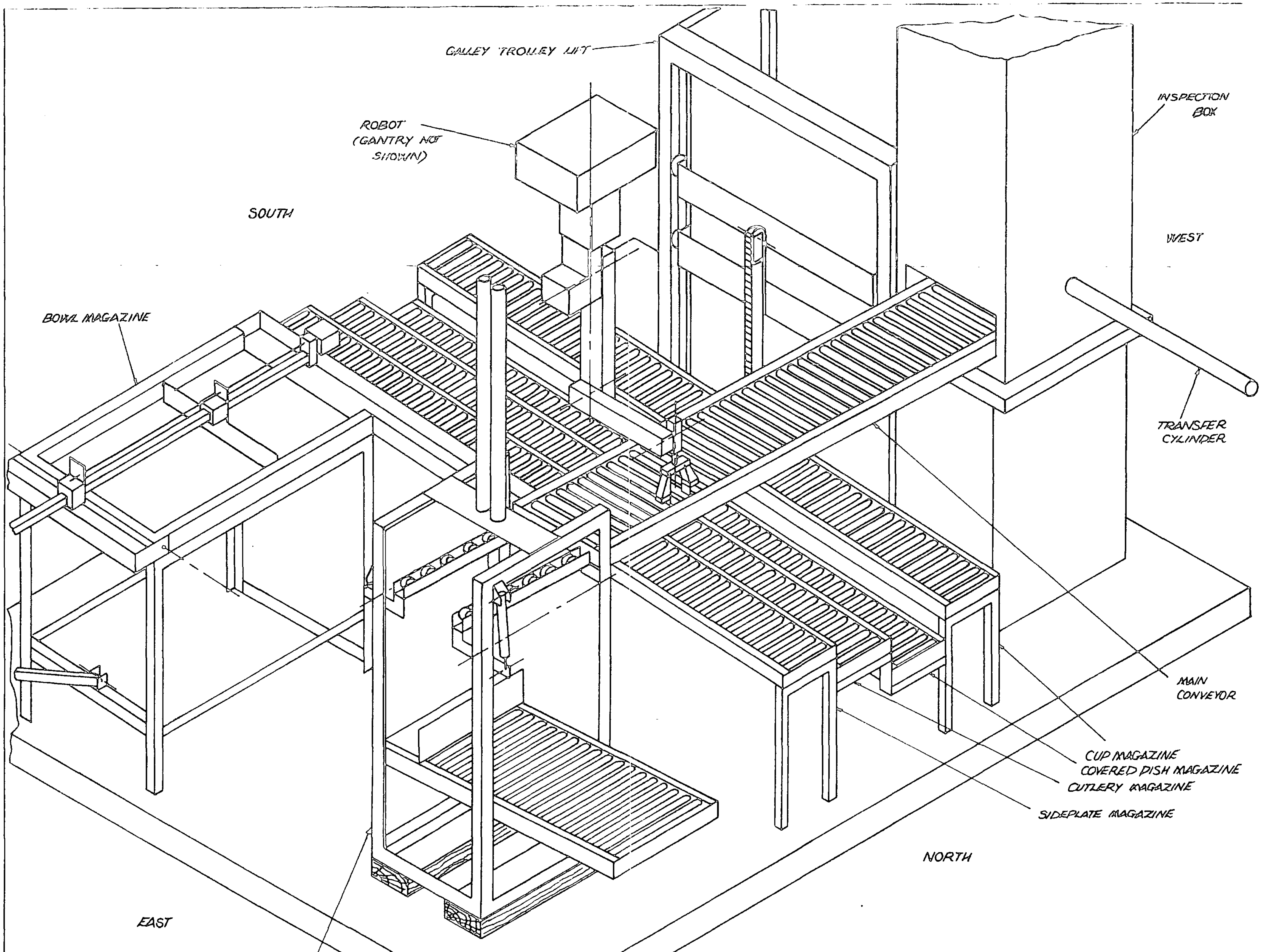
FIGURE 1



CELL (PARALLEL) LAYOUT

PLAN VIEW

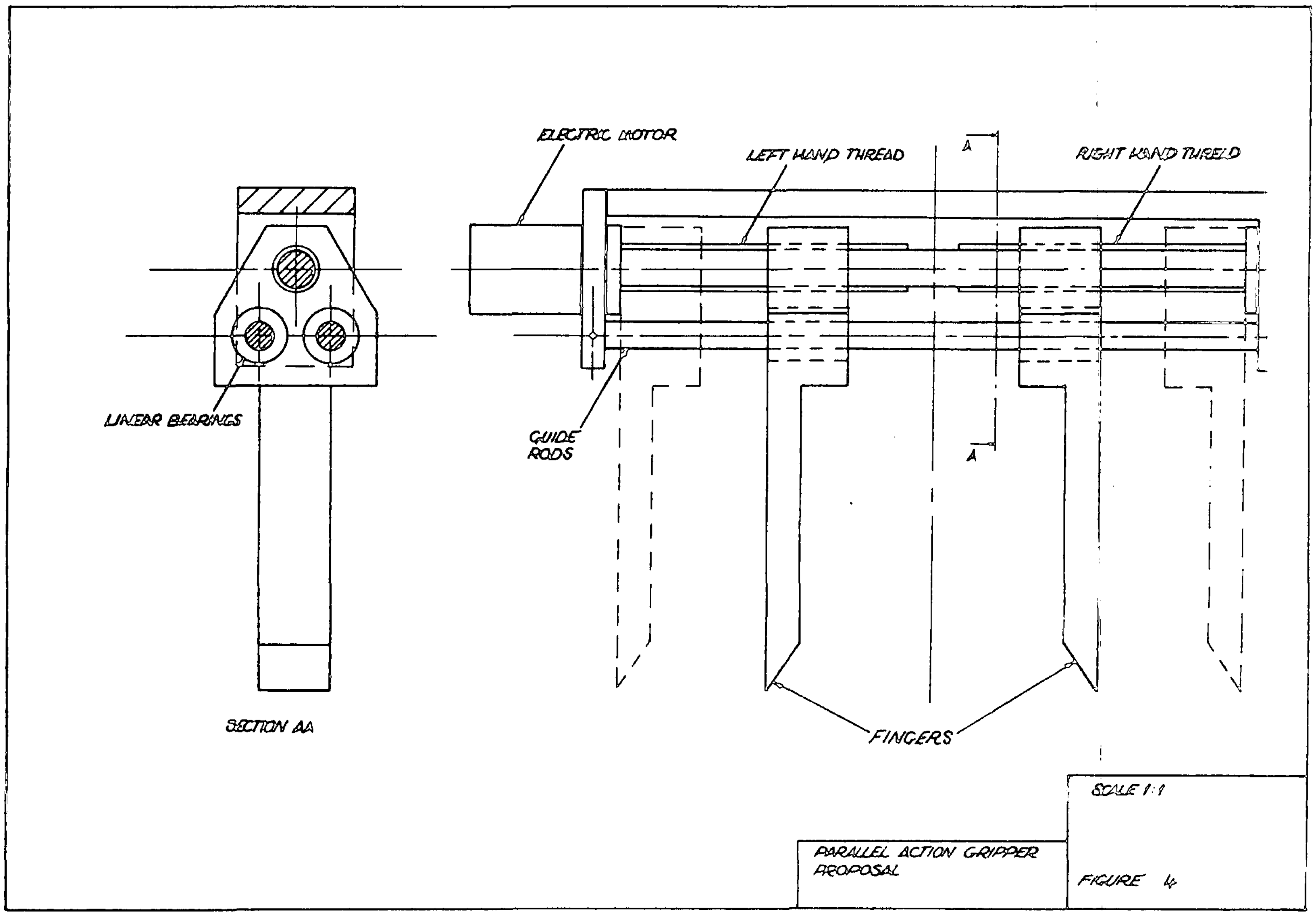
FIGURE 2



NOT TO SCALE

PROTOTYPE ASSEMBLY & TROLLEY LOADING CELLS

FIGURE 3



ELECTRIC MOTOR
LEFT HAND THREAD
RIGHT HAND THREAD
A
A
LINEAR BEARINGS
GUIDE RODS
SECTION AA
FINGERS
SCALE 1:1
PARALLEL ACTION GRIPPER PROPOSAL
FIGURE 4

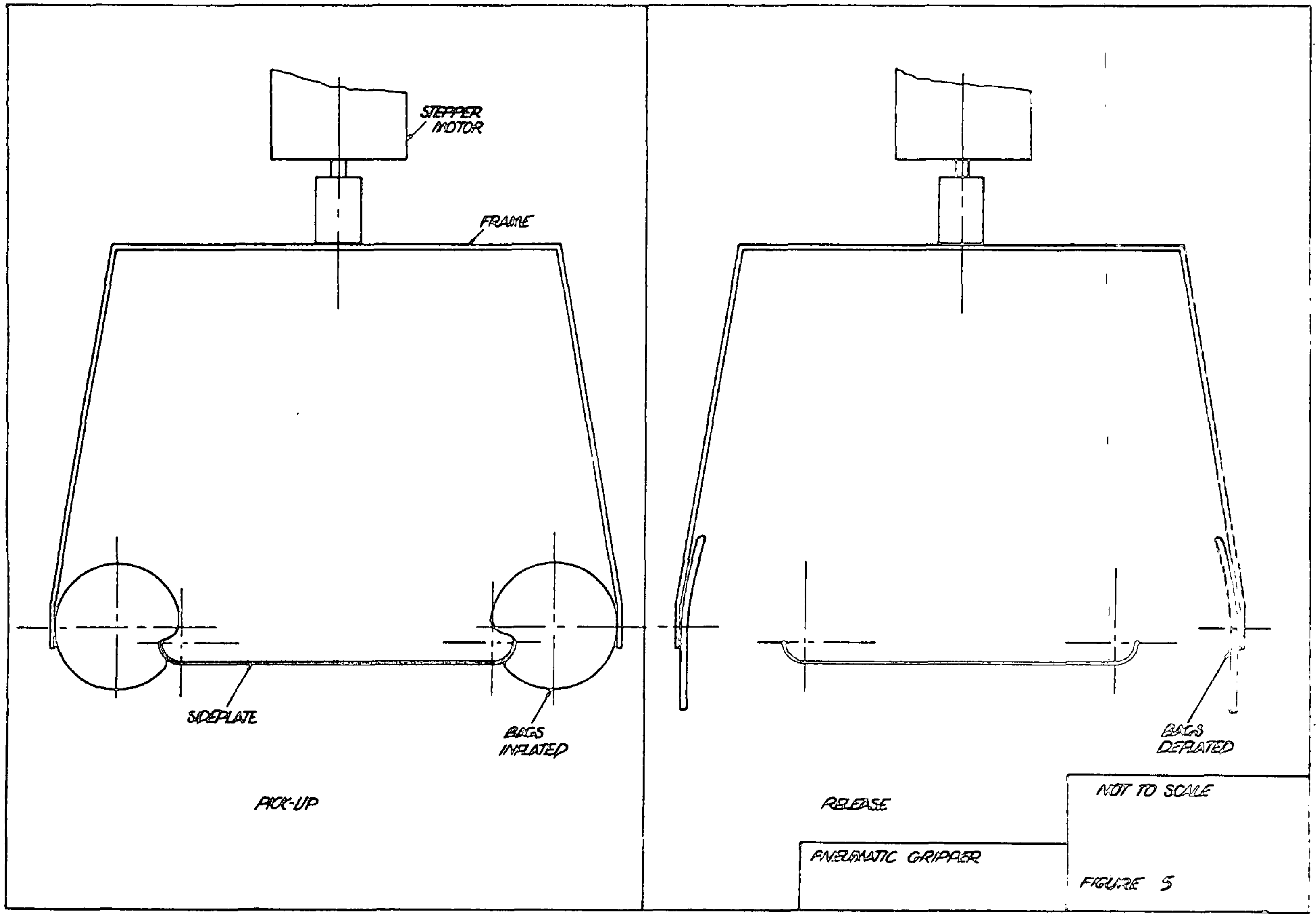
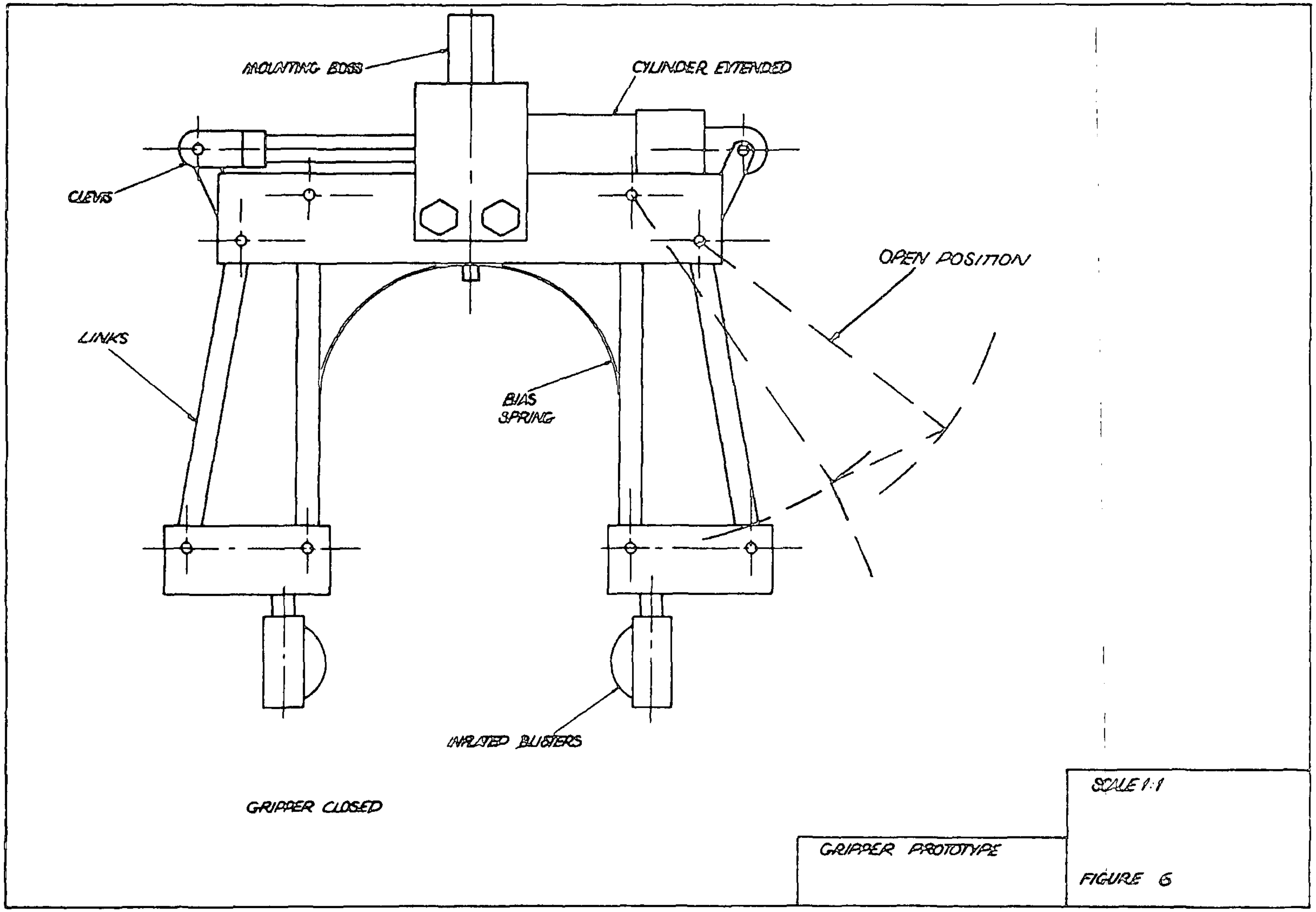
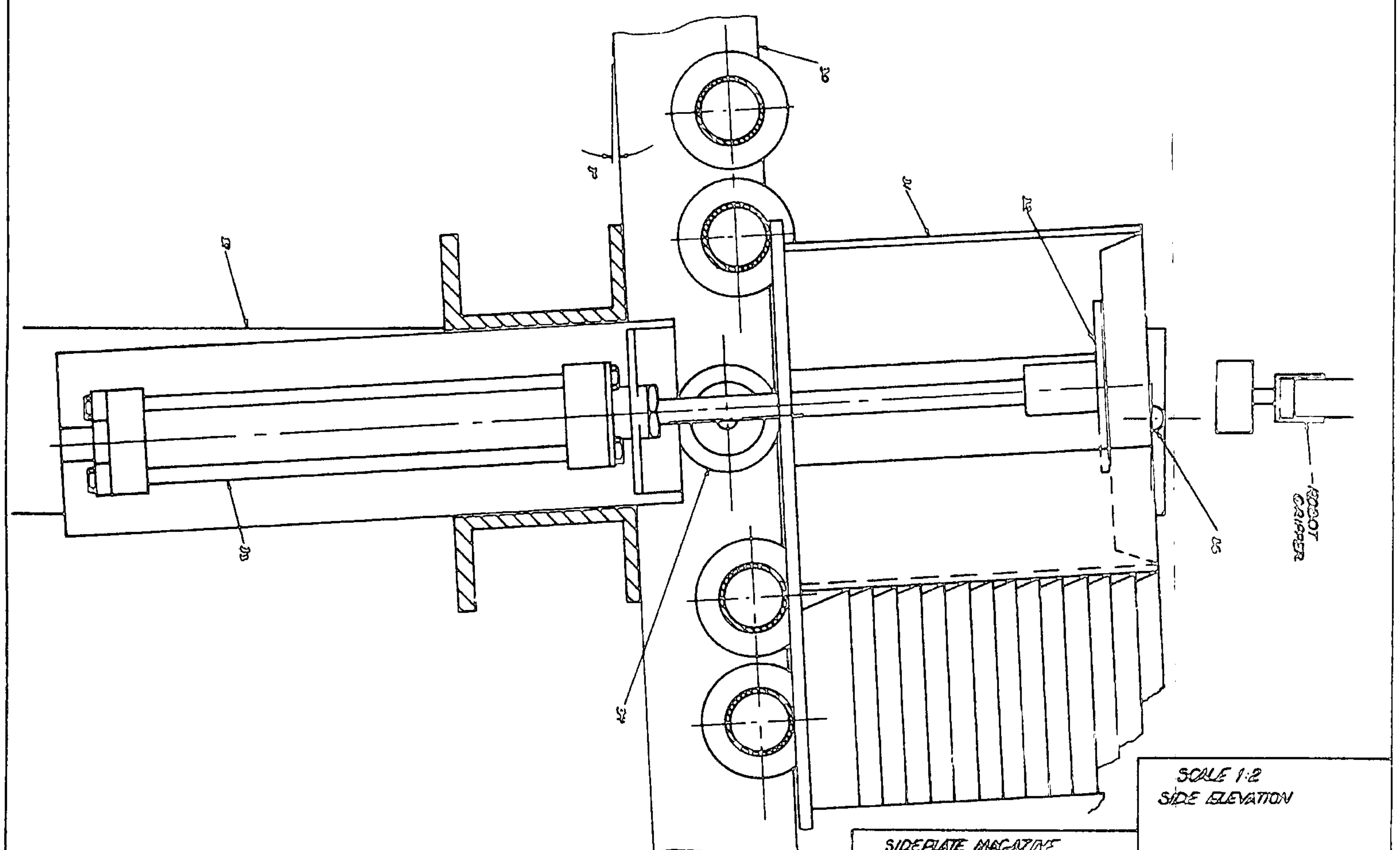

STEPPER MOTOR
FRAME
SIDEPLATE
BAGS INFLATED
PICK-UP
BAGS DEFLATED
RELEASE
NOT TO SCALE
PNEUMATIC GRIPPER

FIGURE 5

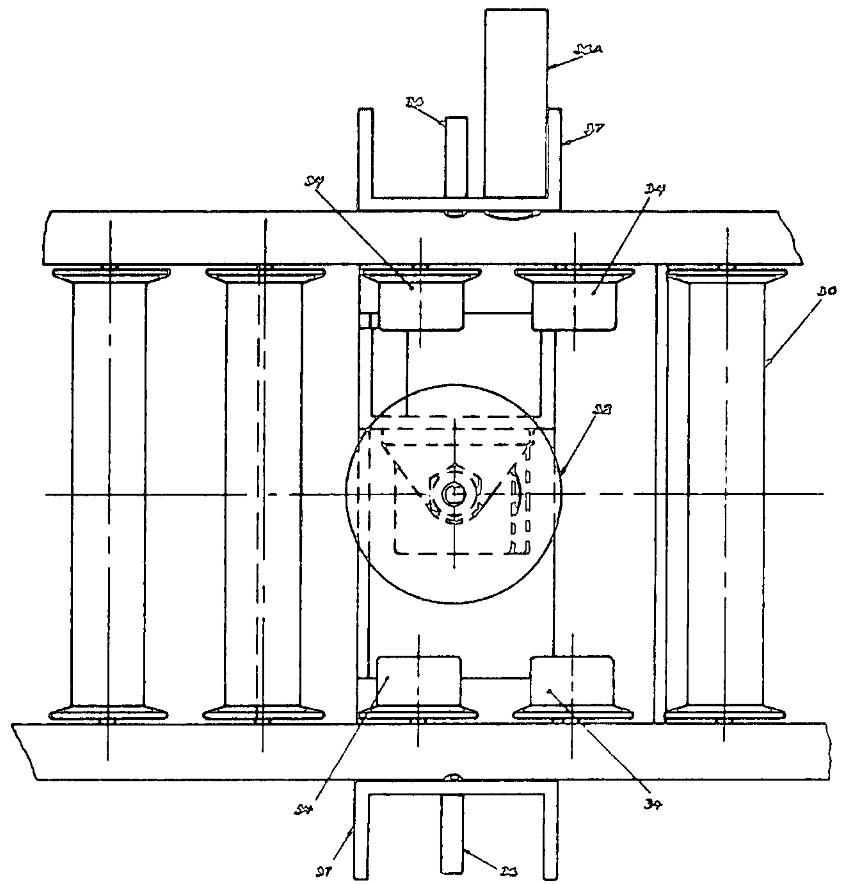

MOUNTING BOSS
CYLINDER EXTENDED
CLEVIS
OPEN POSITION
LINKS
BIAS
SPRING
INFLATED BLISTERS
GRIPPER CLOSED
SCALE 1:1
GRIPPER PROTOTYPE
FIGURE 6



SIDEPLATE MAGAZINE
CROSS SECTION

SCALE 1:2
SIDE ELEVATION

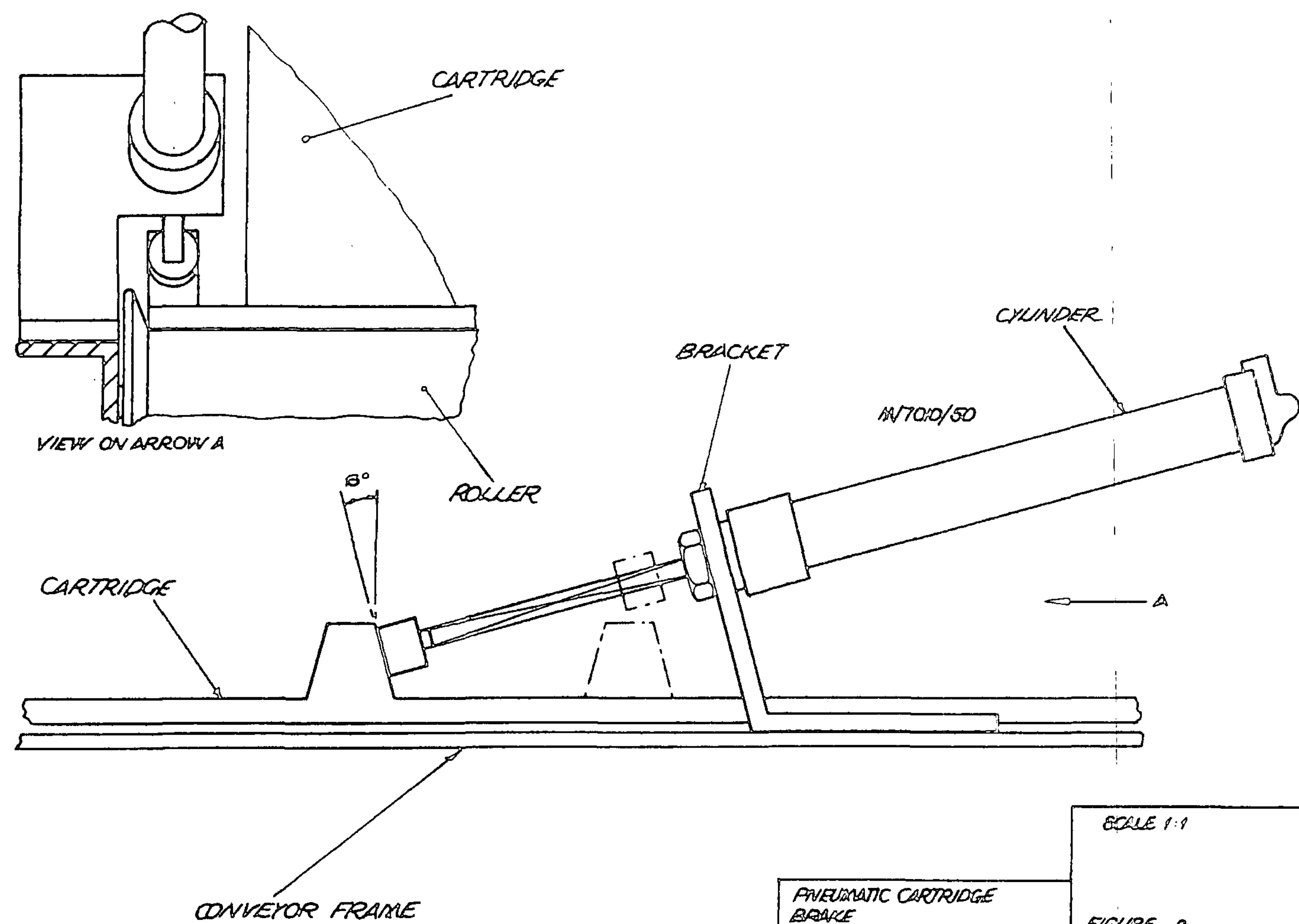
FIGURE 7



SIDE PLATE MAGAZINE
-REDESIGN PLAN VIEW

SCALE 1:2

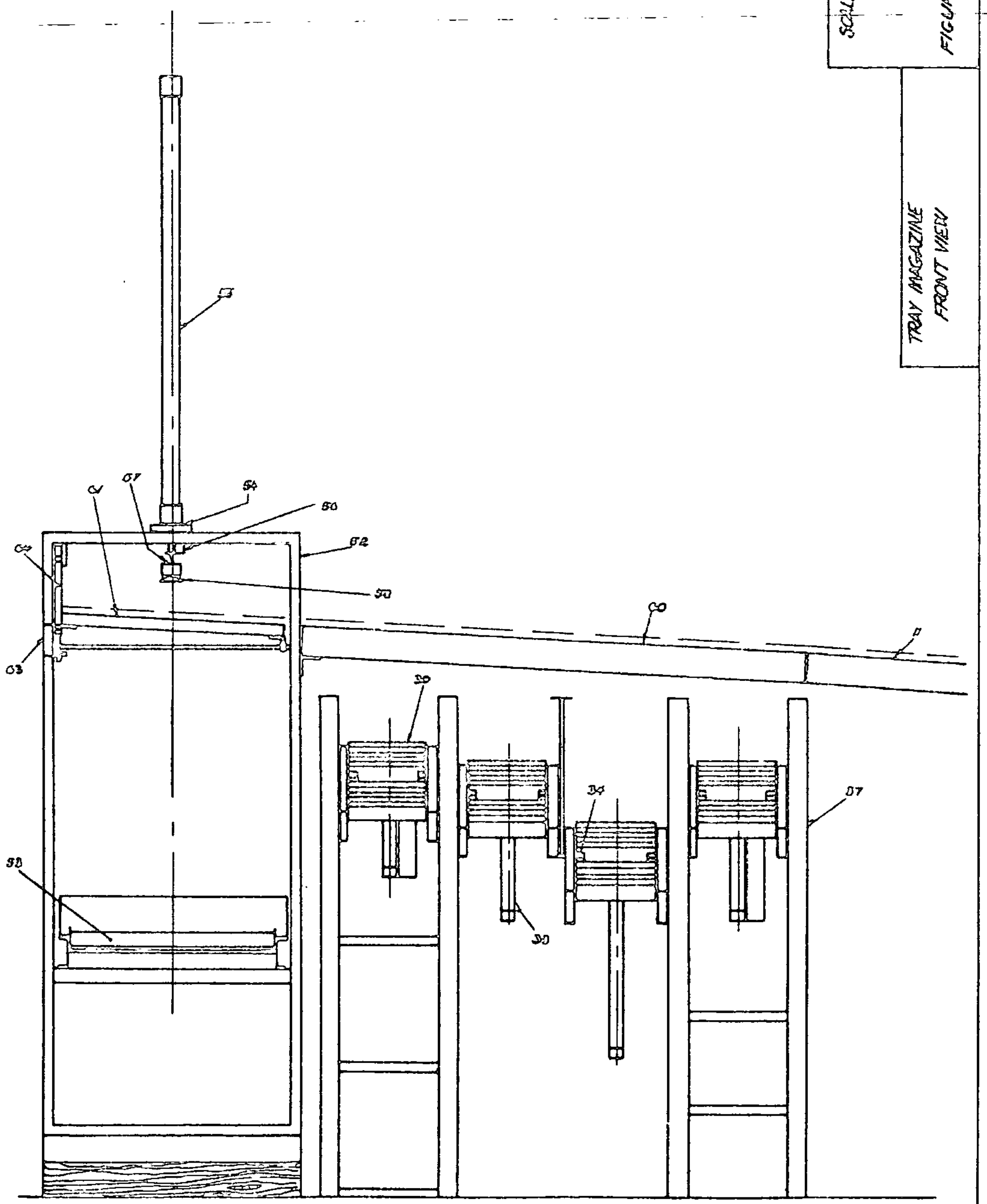
FIGURE 8



PNEUMATIC CARTRIDGE BRAKE

SCALE 1:1

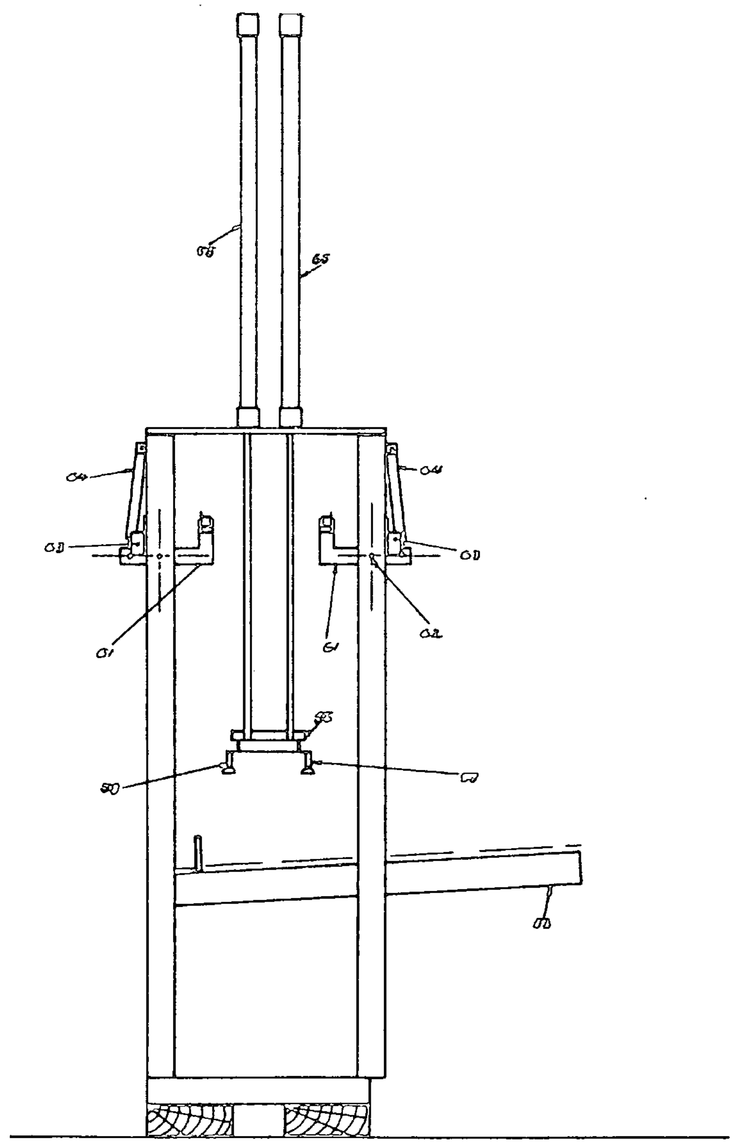
FIGURE 9



SCALE 1:10

FIGURE 10a

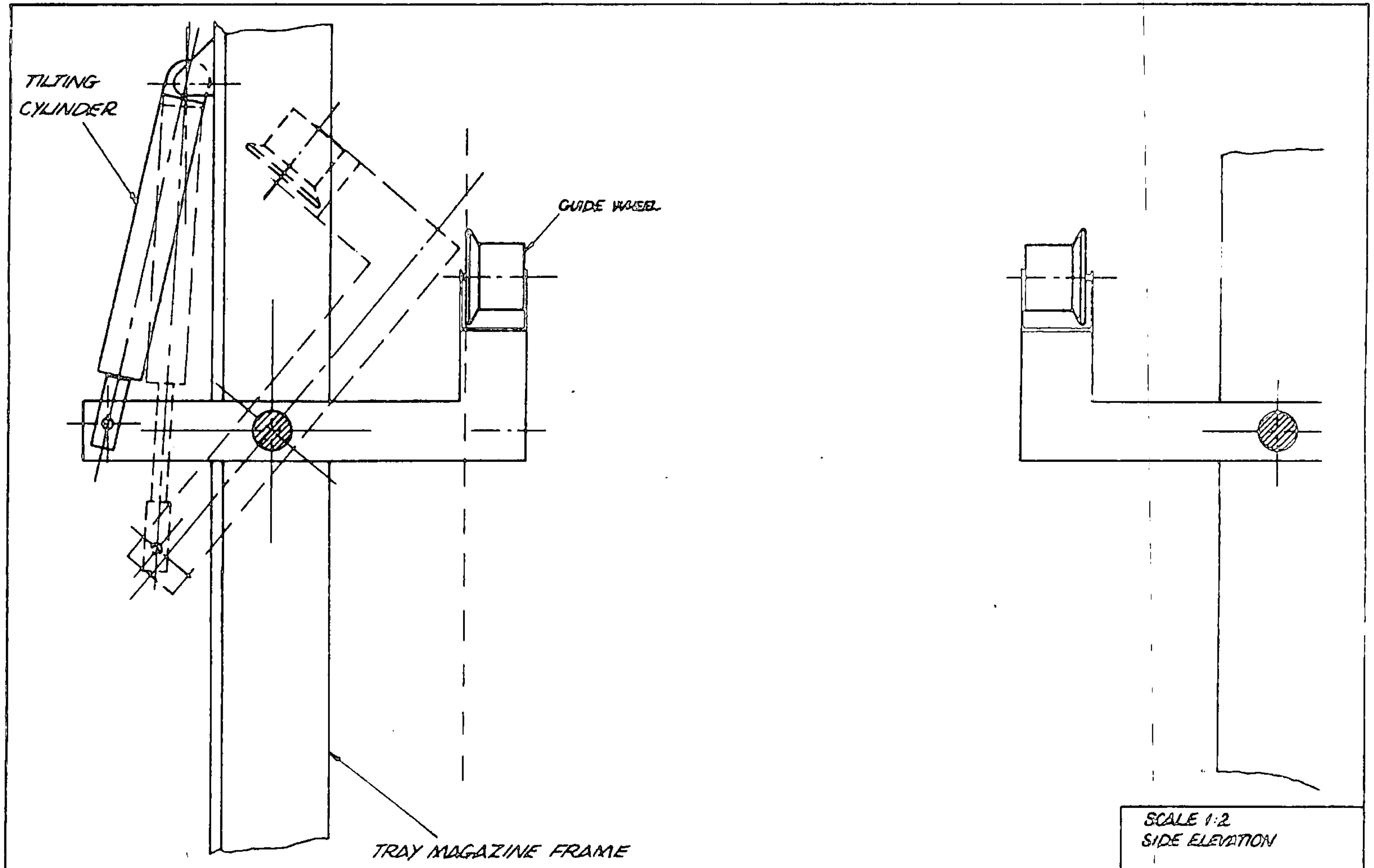
TRAY MAGAZINE
FRONT VIEW



SCALE 1:10

FIGURE 10b

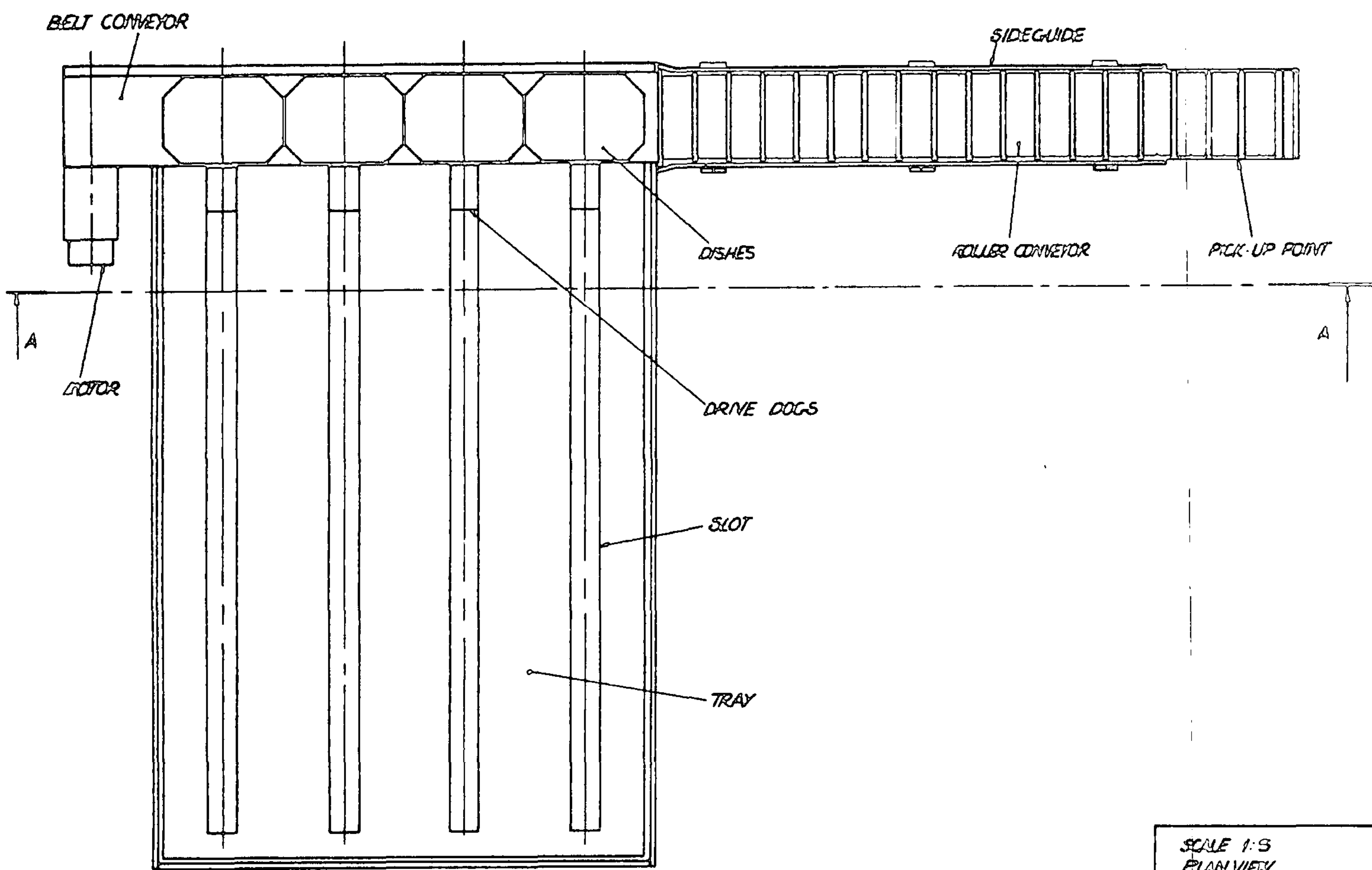
TRAY MAGAZINE
SIDE ELEVATION



TRAY MAGAZINE TRACK TILTING
ARRANGEMENT

SCALE 1:2
SIDE ELEVATION

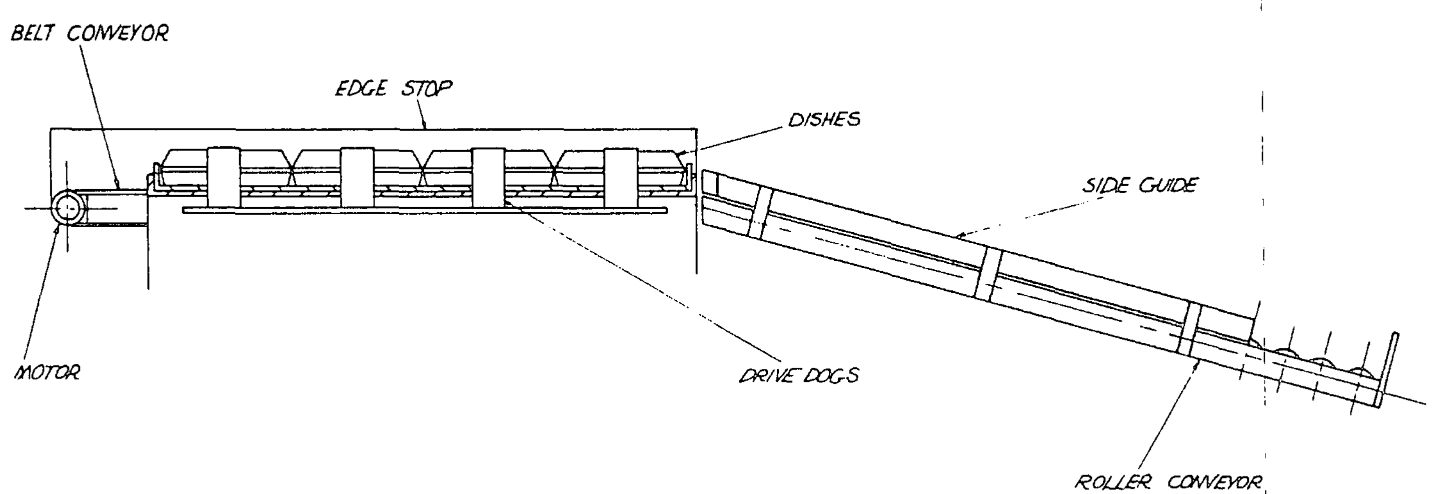
FIGURE 11



GENERAL VIEW OF DISH MAGAZINE

SCALE 1:5
PLAN VIEW

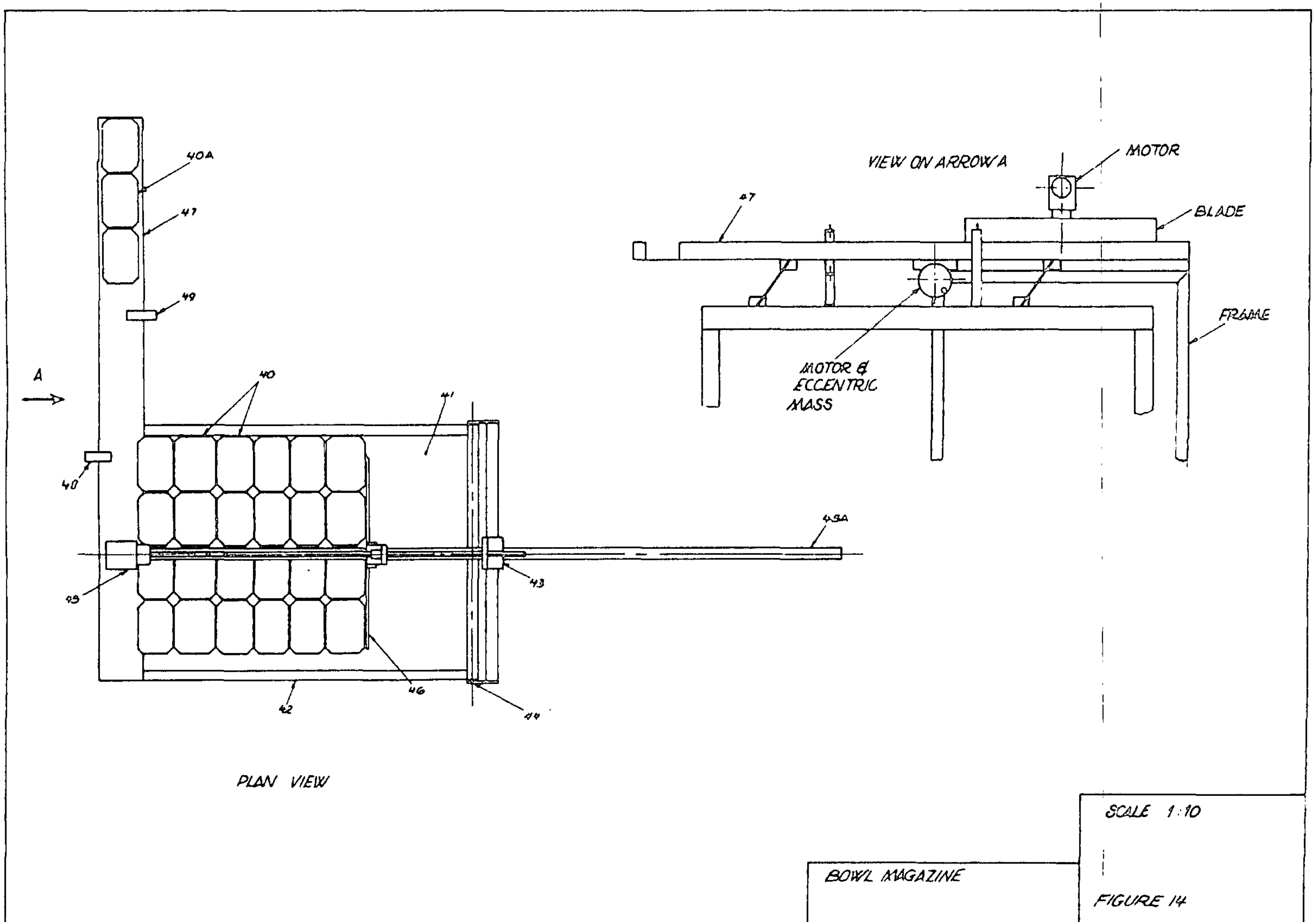
FIGURE 12

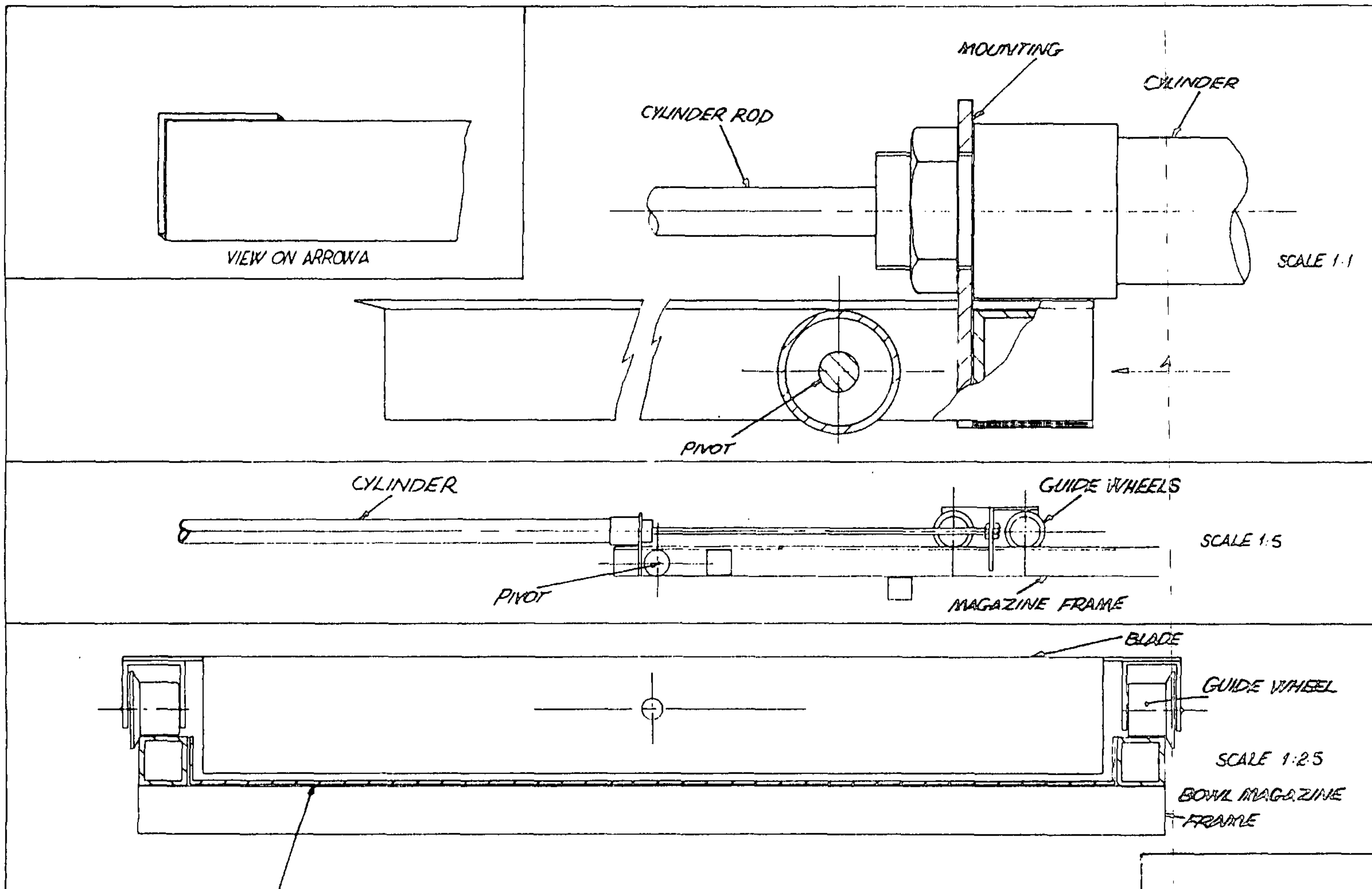


SECTION AA
DISH MAGAZINE

SCALE 1:5

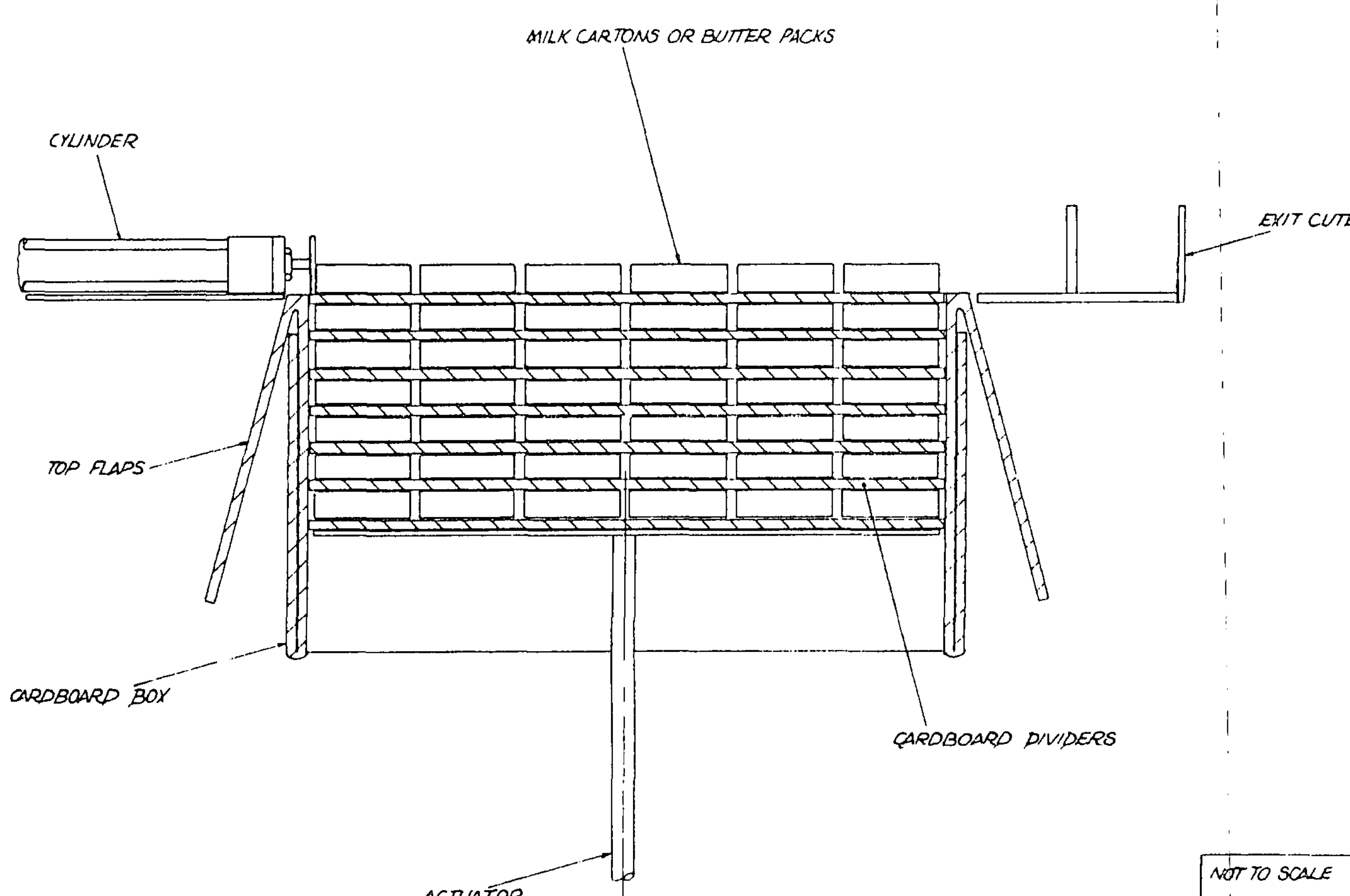
FIGURE 13


VIEW ON ARROW A
MOTOR
BLADE
47
FRAME
MOTOR & ECCENTRIC MASS
A
40A
47
49
40
41
40
45A
43
45
46
42
44
PLAN VIEW
SCALE 1:10
BOWL MAGAZINE
FIGURE 14



BOWL MAGAZINE - BLADE GUIDE PROPOSAL

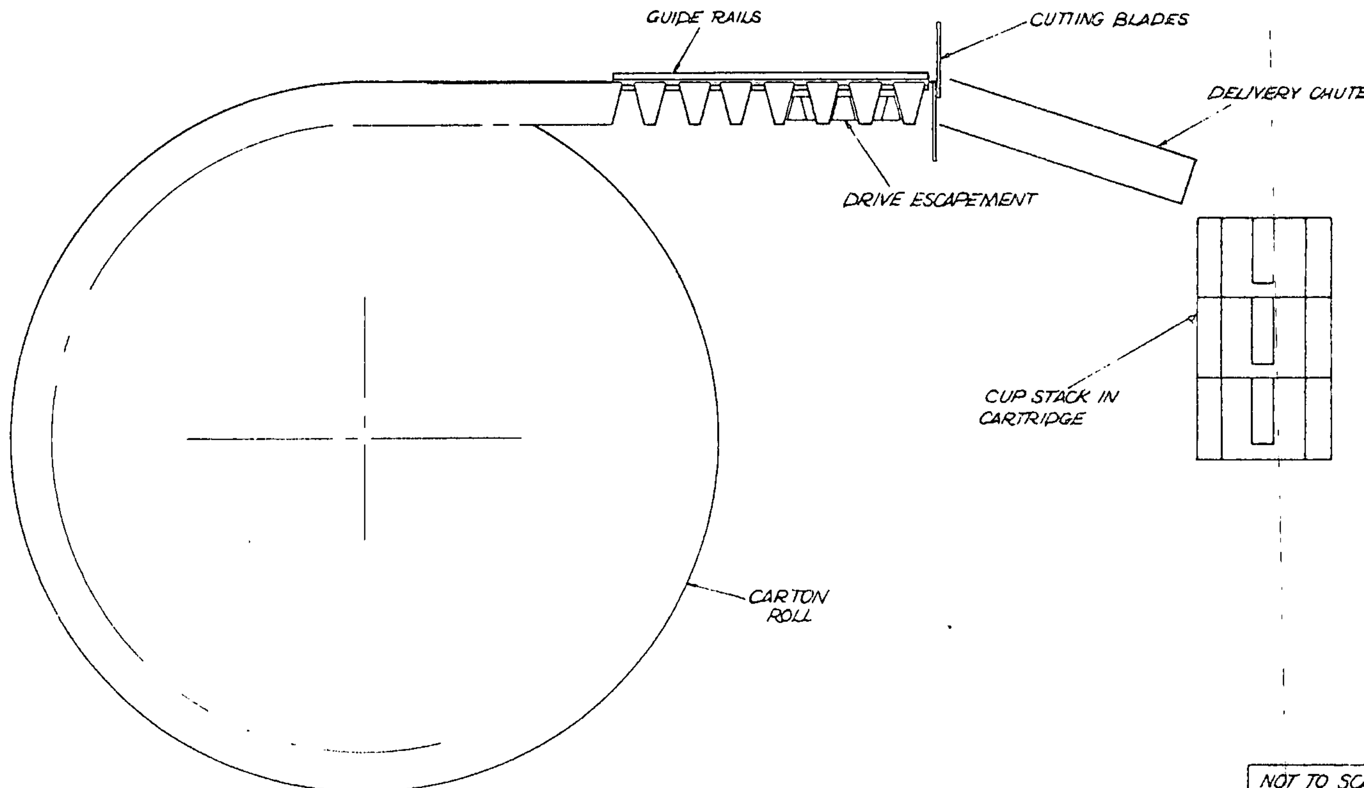
FIGURE 15



NOT TO SCALE

MILK OR BUTTER MAGAZINE PROPOSAL

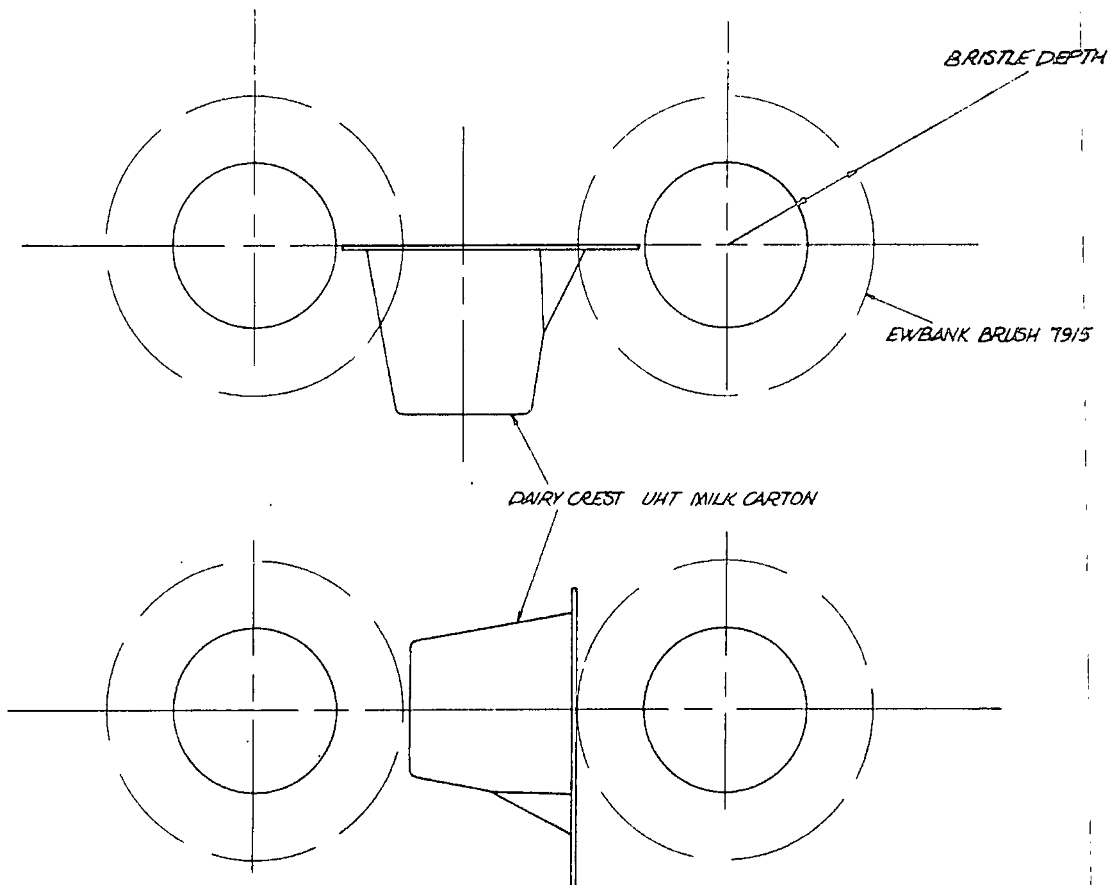
FIGURE 16



NOT TO SCALE

MILK CARTON MAGAZINE PROPOSAL

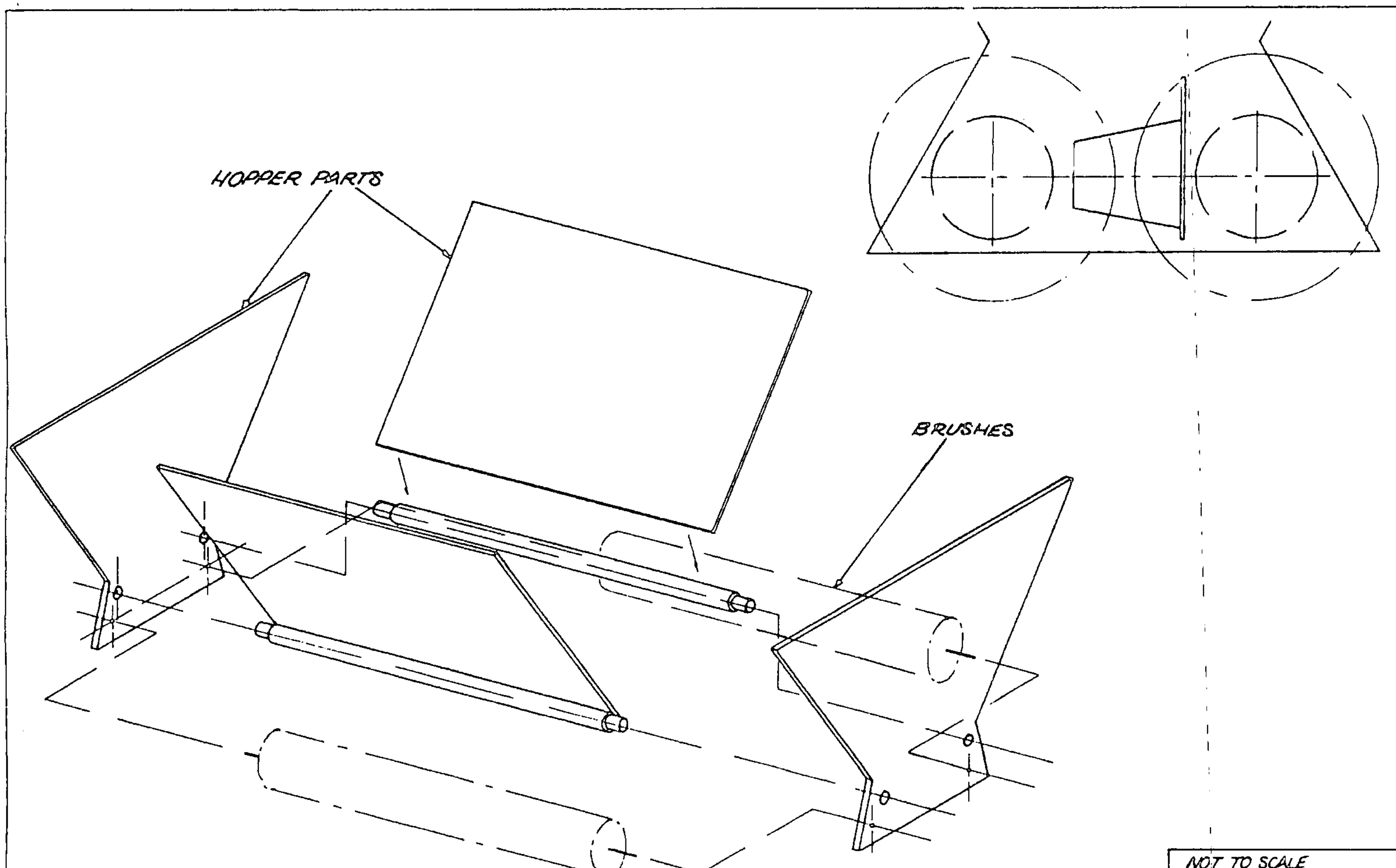
FIGURE 17



MILK CARTON MAGAZINE
BRUSH OPERATION

SCALE 1:1

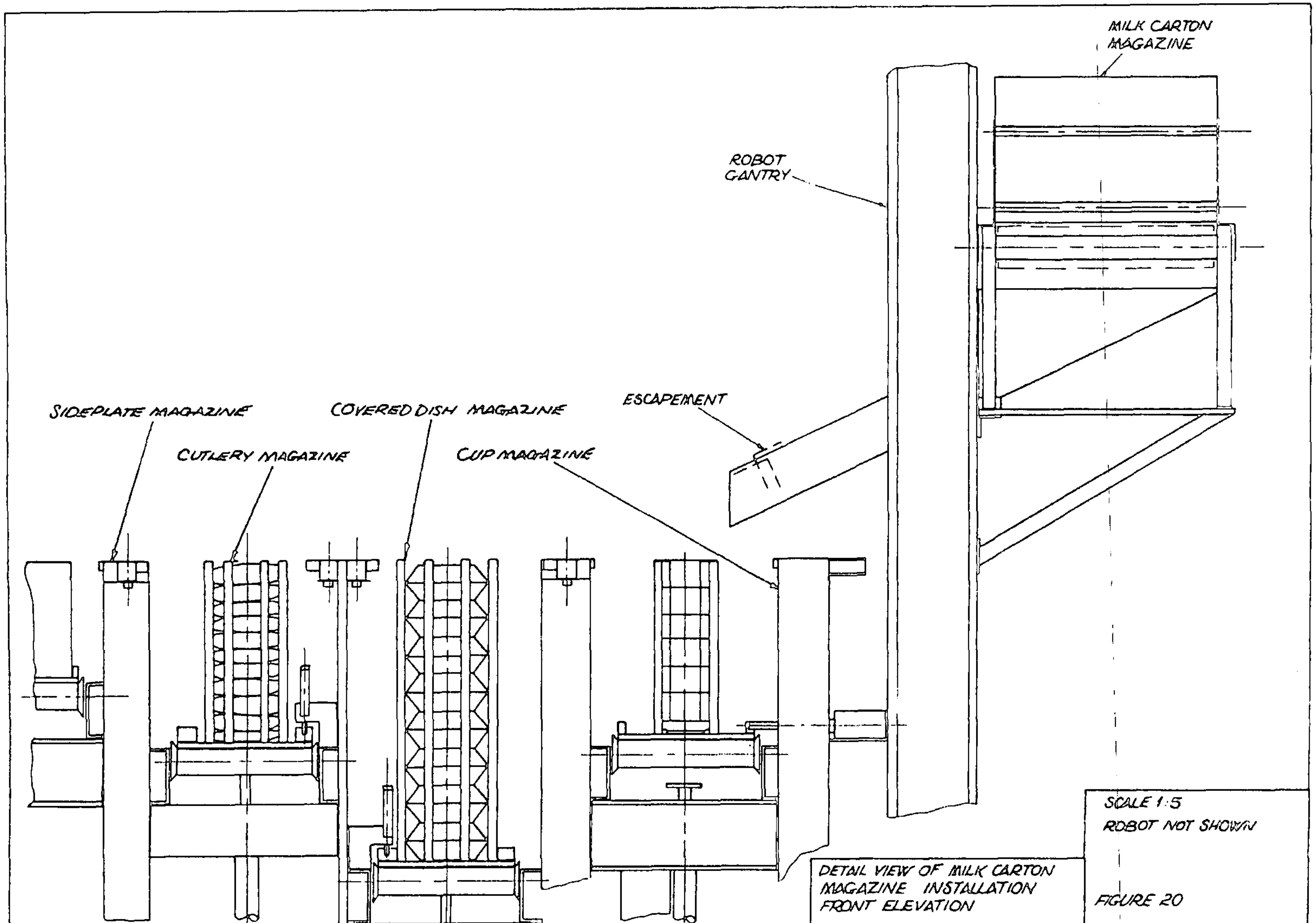
FIGURE 18



MILK CARTON MAGAZINE
ASSEMBLY DRAWING

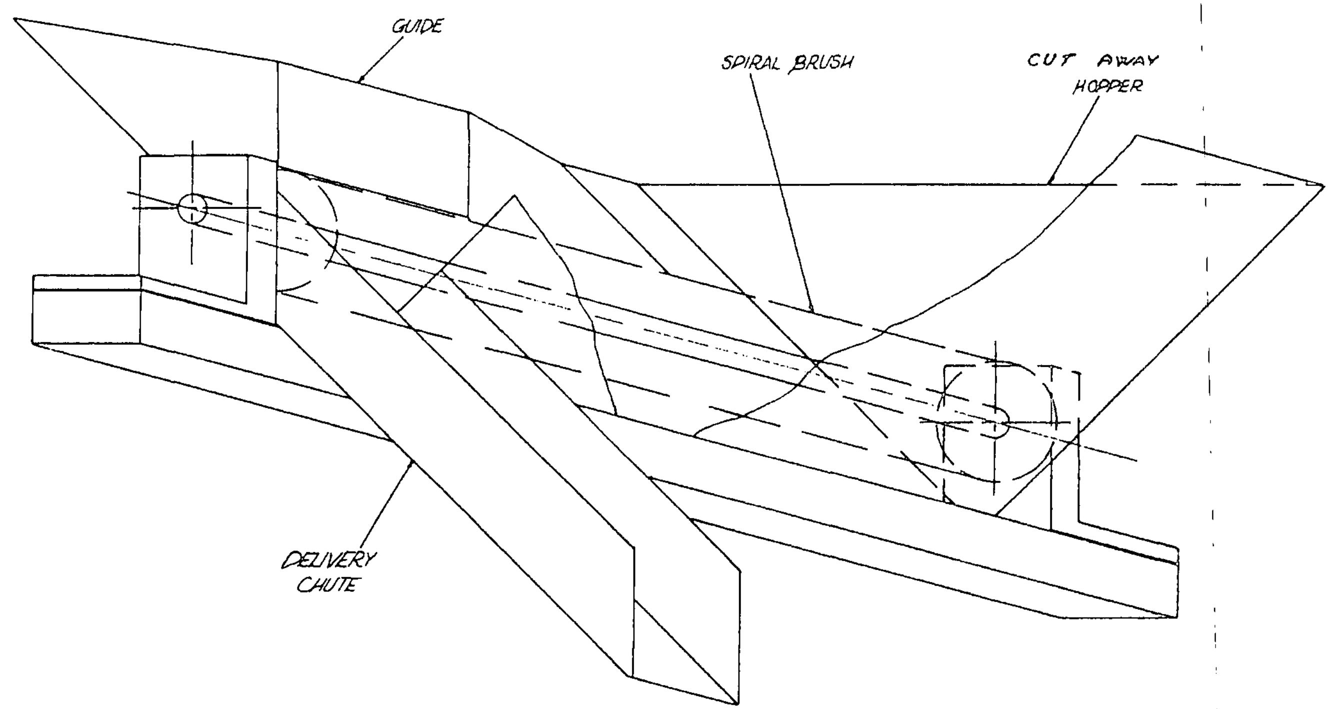
NOT TO SCALE

FIGURE 19



DETAIL VIEW OF MILK CARTON MAGAZINE INSTALLATION FRONT ELEVATION

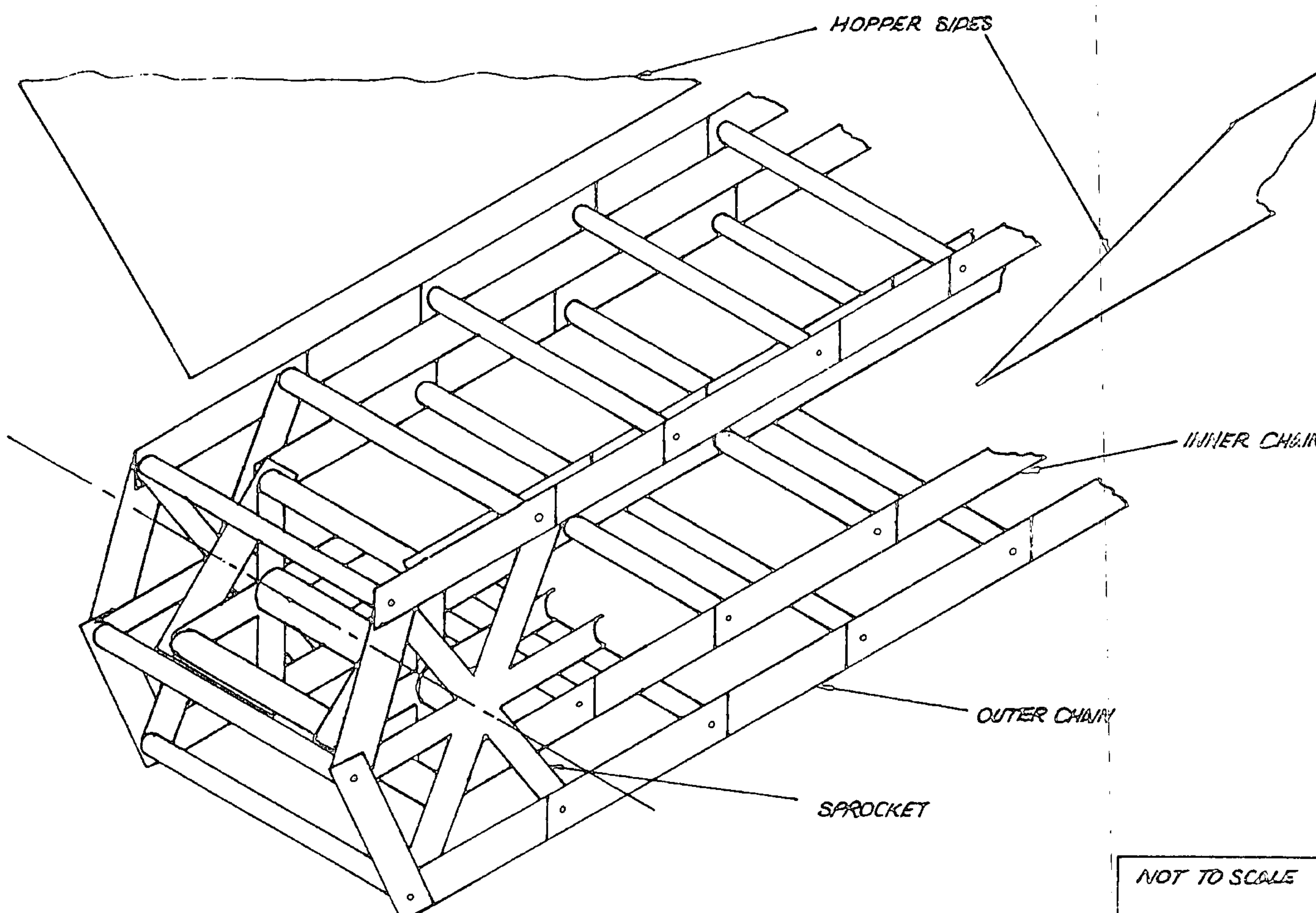
FIGURE 20



NOT TO SCALE

MILK CARTON MAGAZINE
PROPOSAL

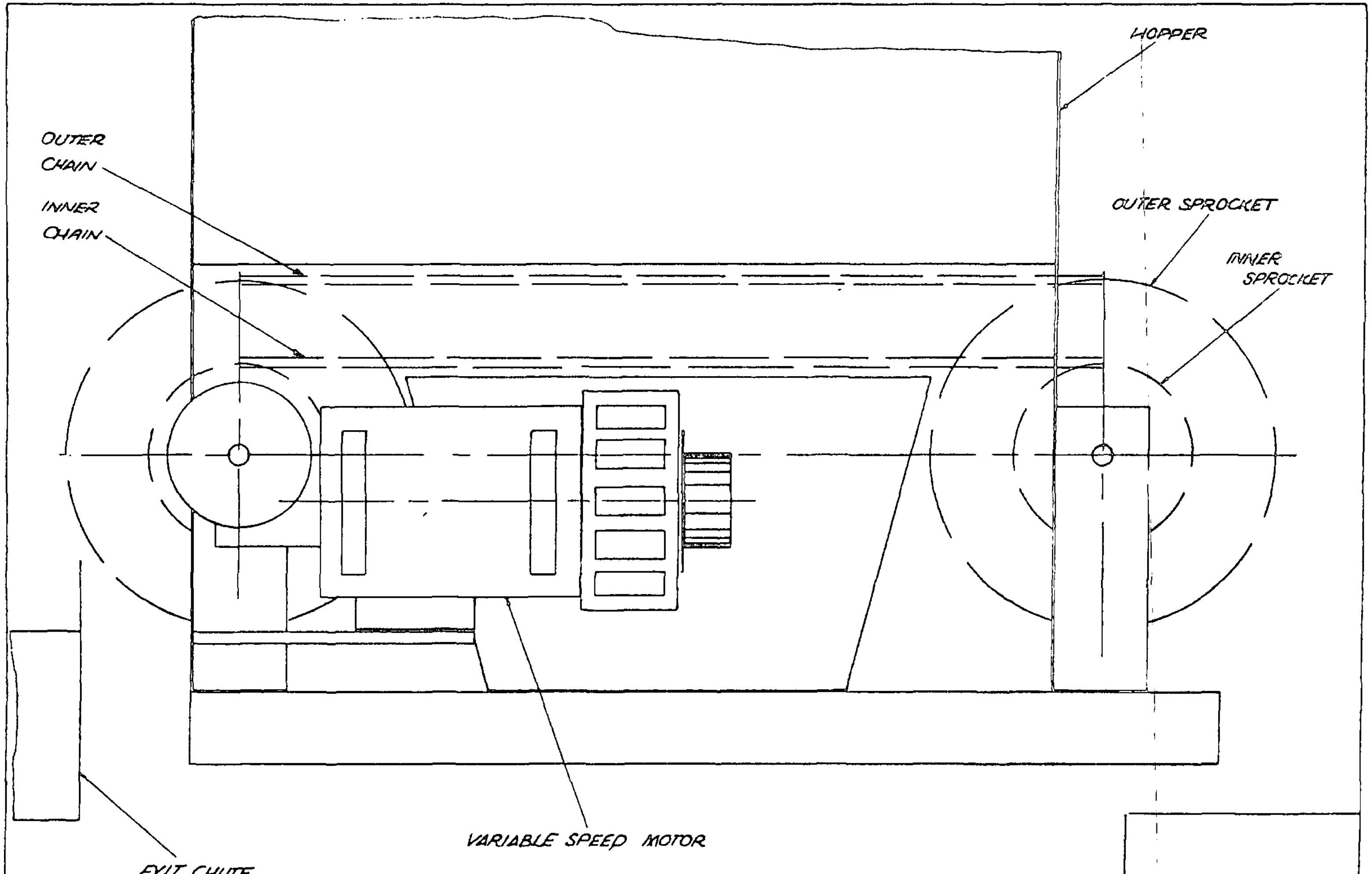
FIGURE 21



FLEXIBLE MAGAZINE CHAIN

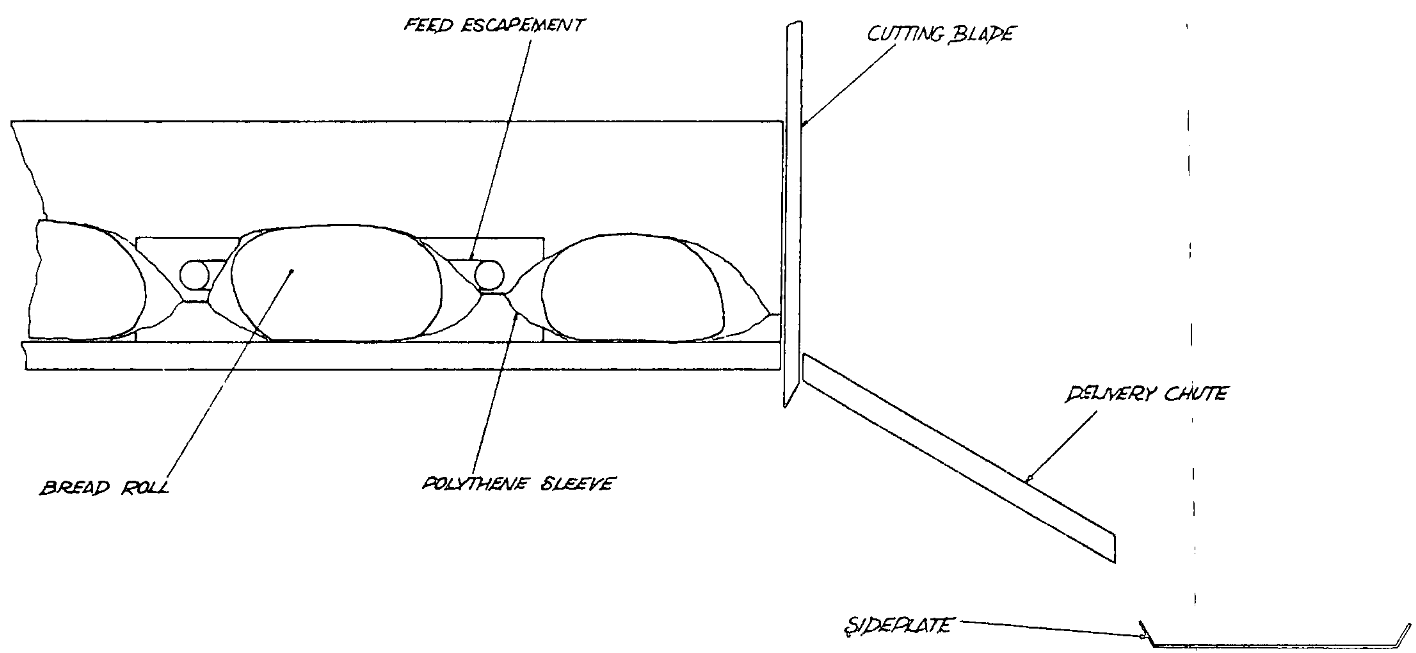
NOT TO SCALE

FIGURE 22



FLEXIBLE MAGAZINE

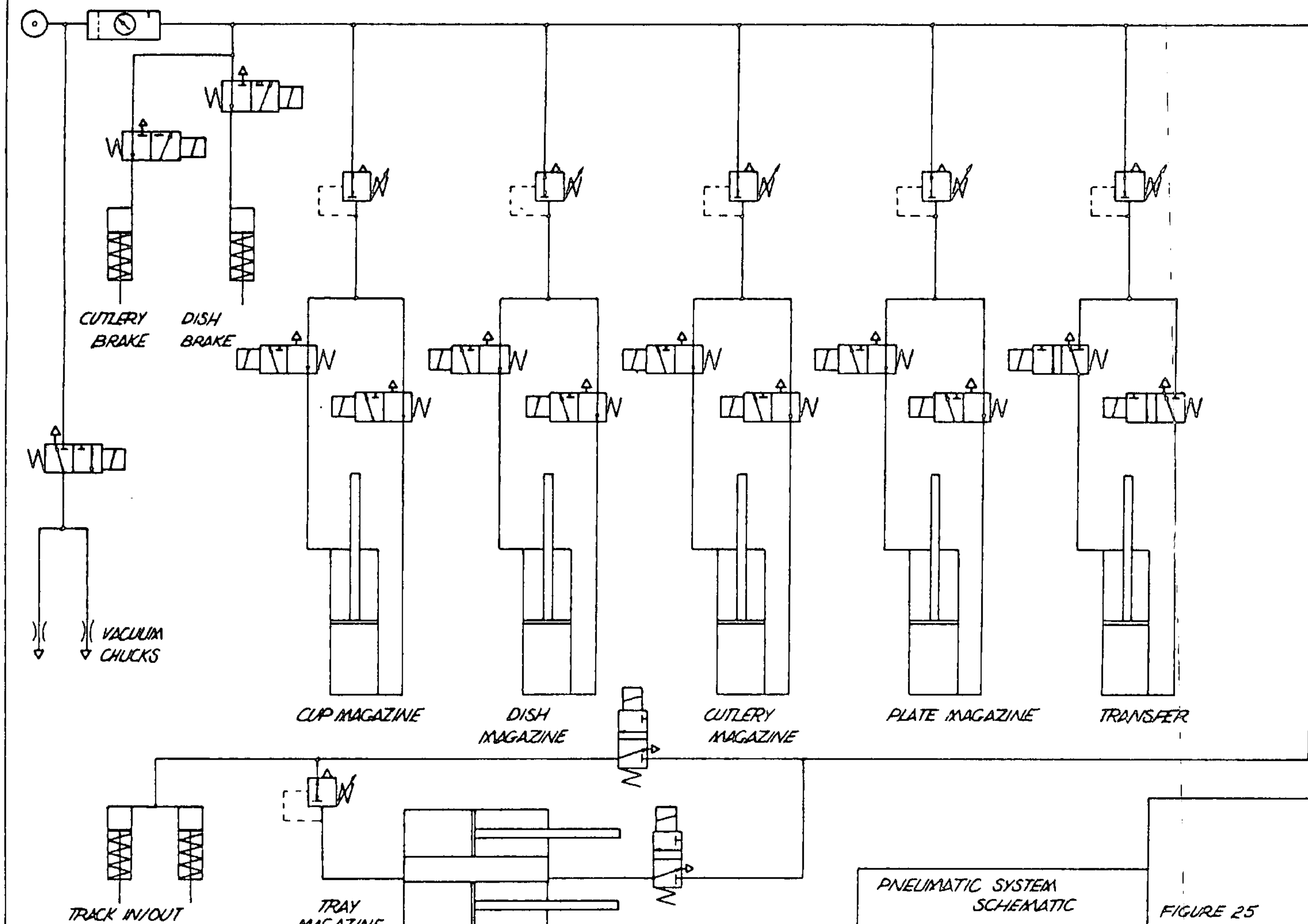
FIGURE 23



NOT TO SCALE

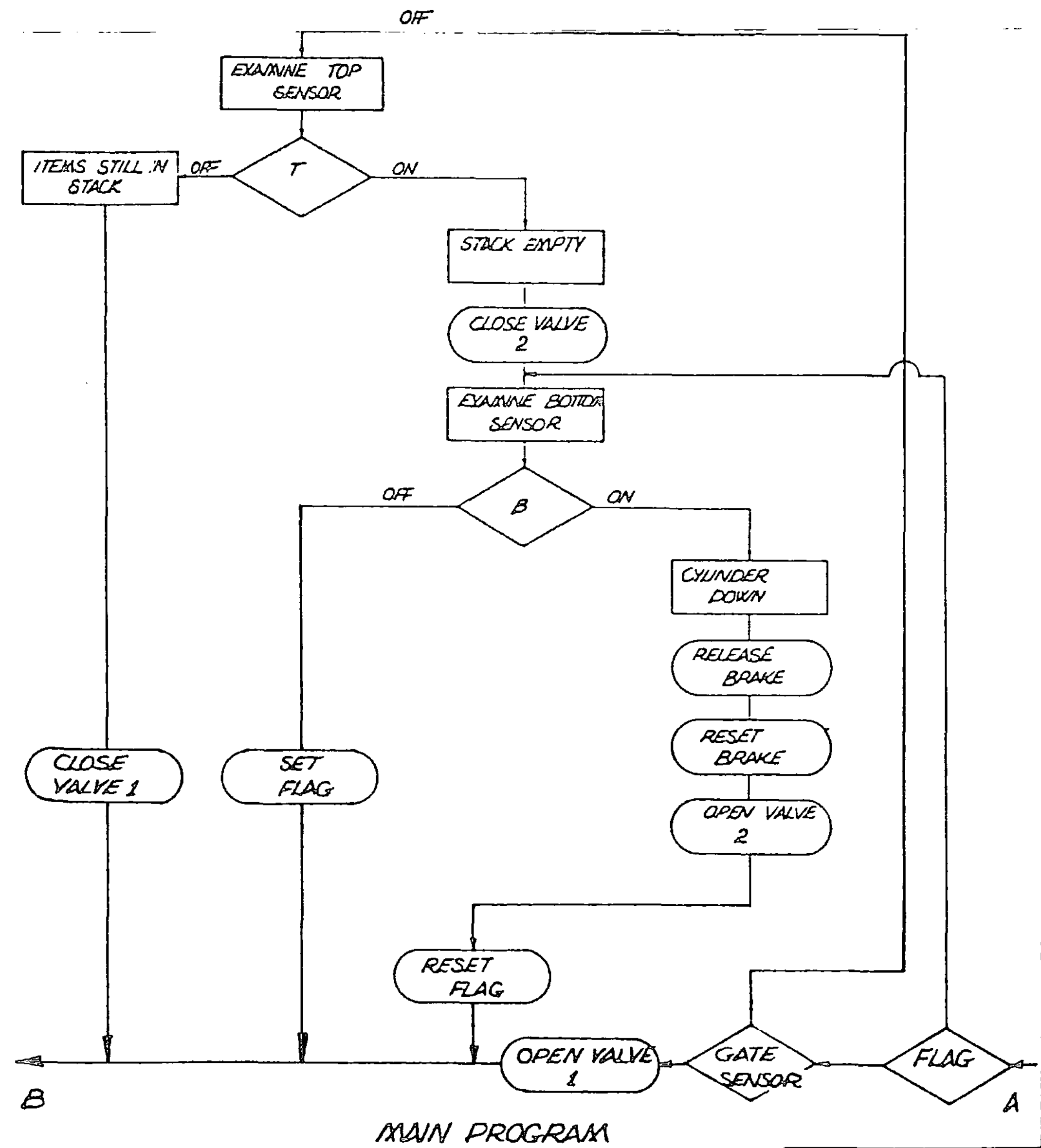
BREAD ROLL MAGAZINE PROPOSAL

FIGURE 24



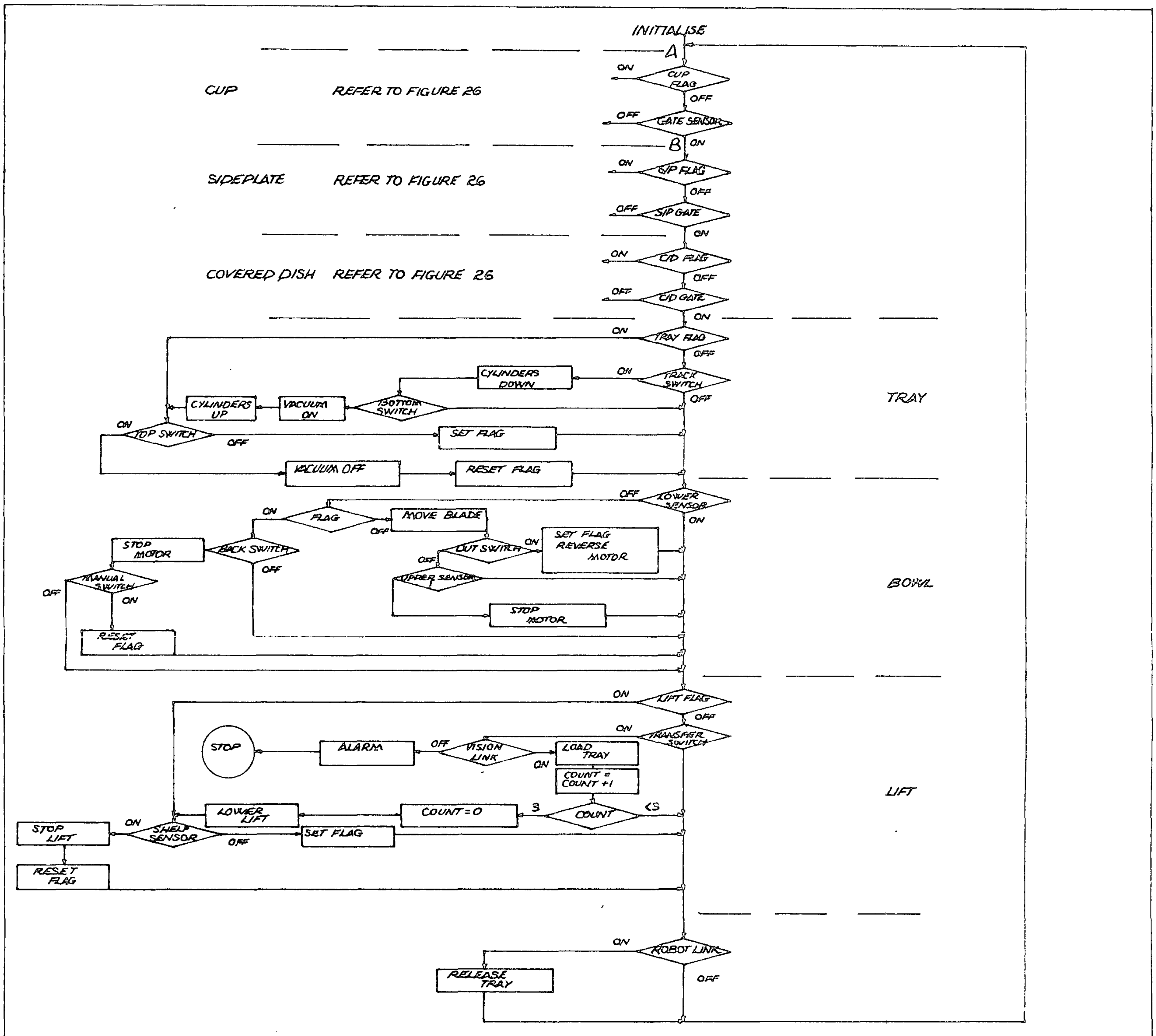
PNEUMATIC SYSTEM SCHEMATIC

FIGURE 25



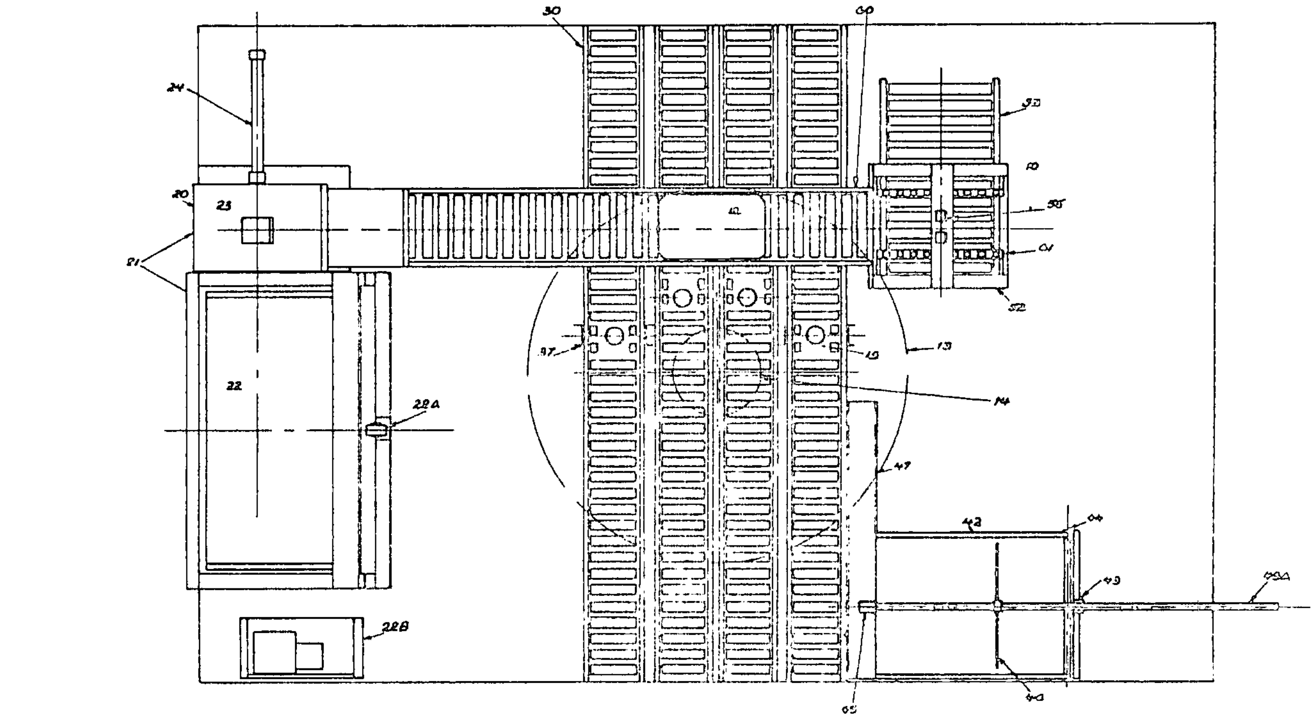
CONTROL SYSTEM FLOW DIAGRAM CARTRIDGE MAGAZINE

FIGURE 26



COMPLETE SYSTEM FLOW DIAGRAM

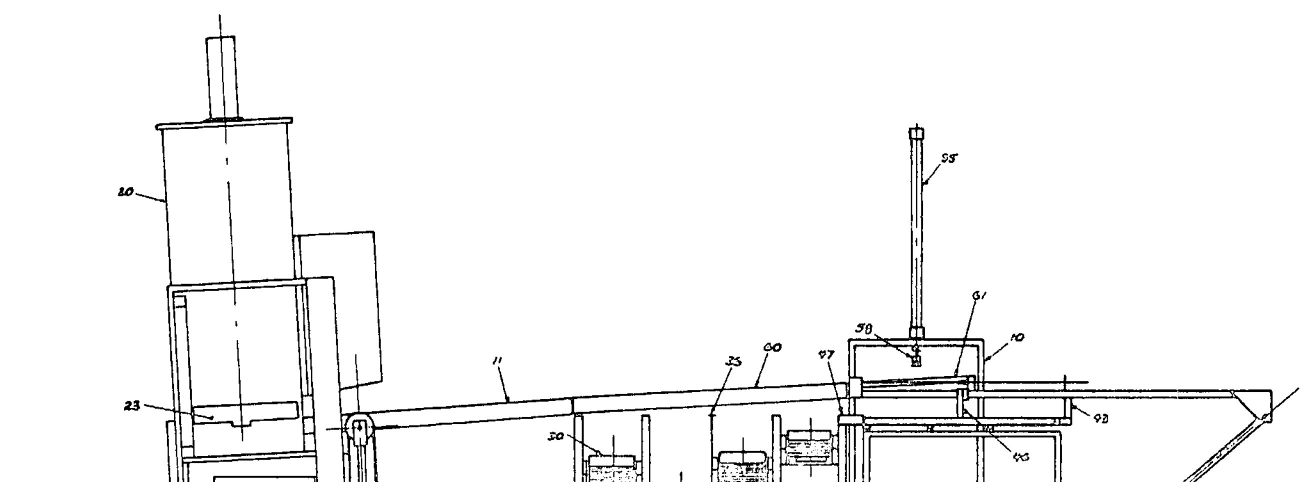
FIGURE 27



SCALE 1:20
ROBOT NOT SHOWN

PROTOTYPE ASSEMBLY & TROLLEY
LOADING CELLS
PLAN VIEW

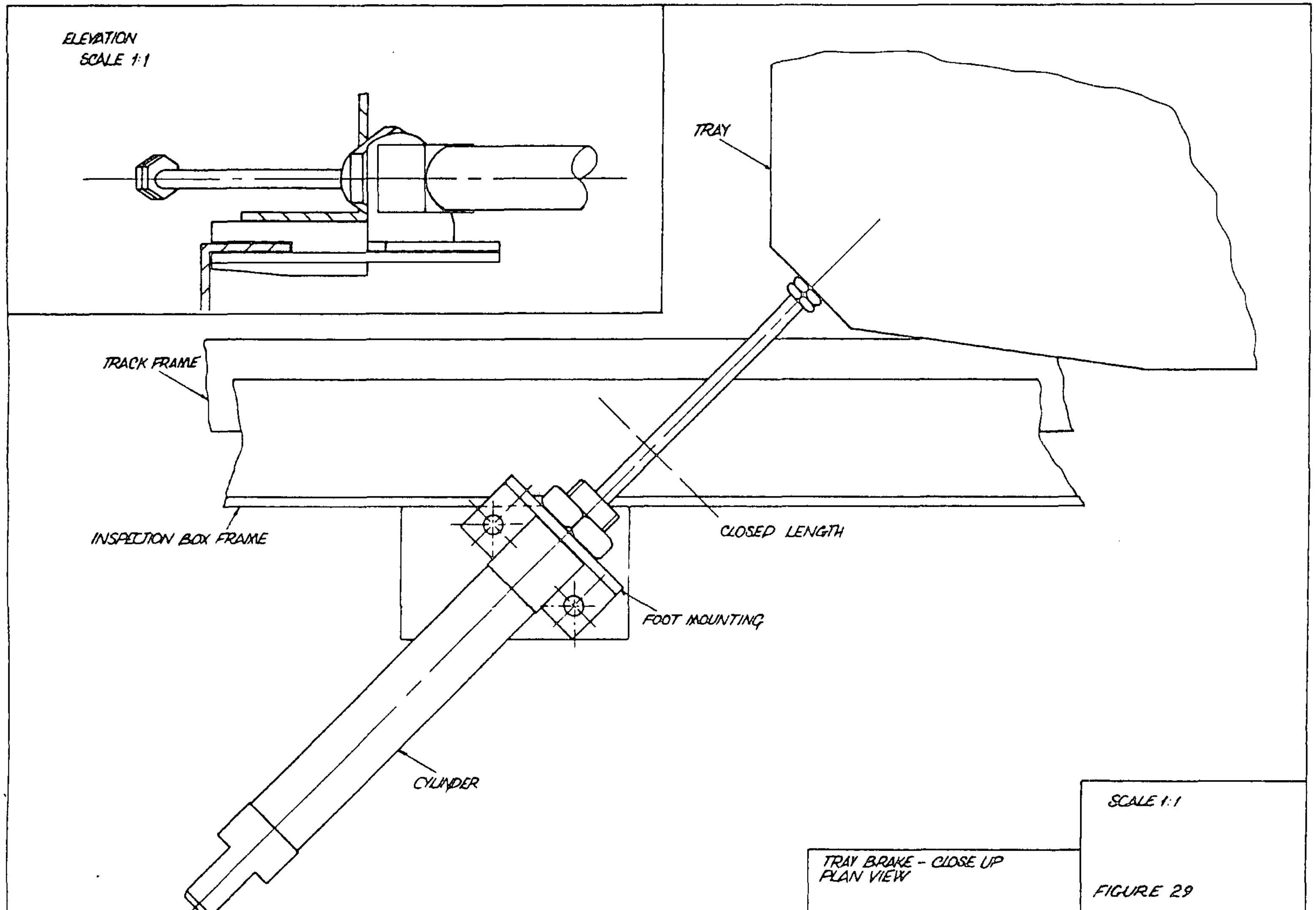
FIGURE 28a



SCALE 1:20
ROBOT NOT SHOWN

PROTOTYPE ASSEMBLY AND
TROLLEY LOADING CELLS
BACK ELEVATION

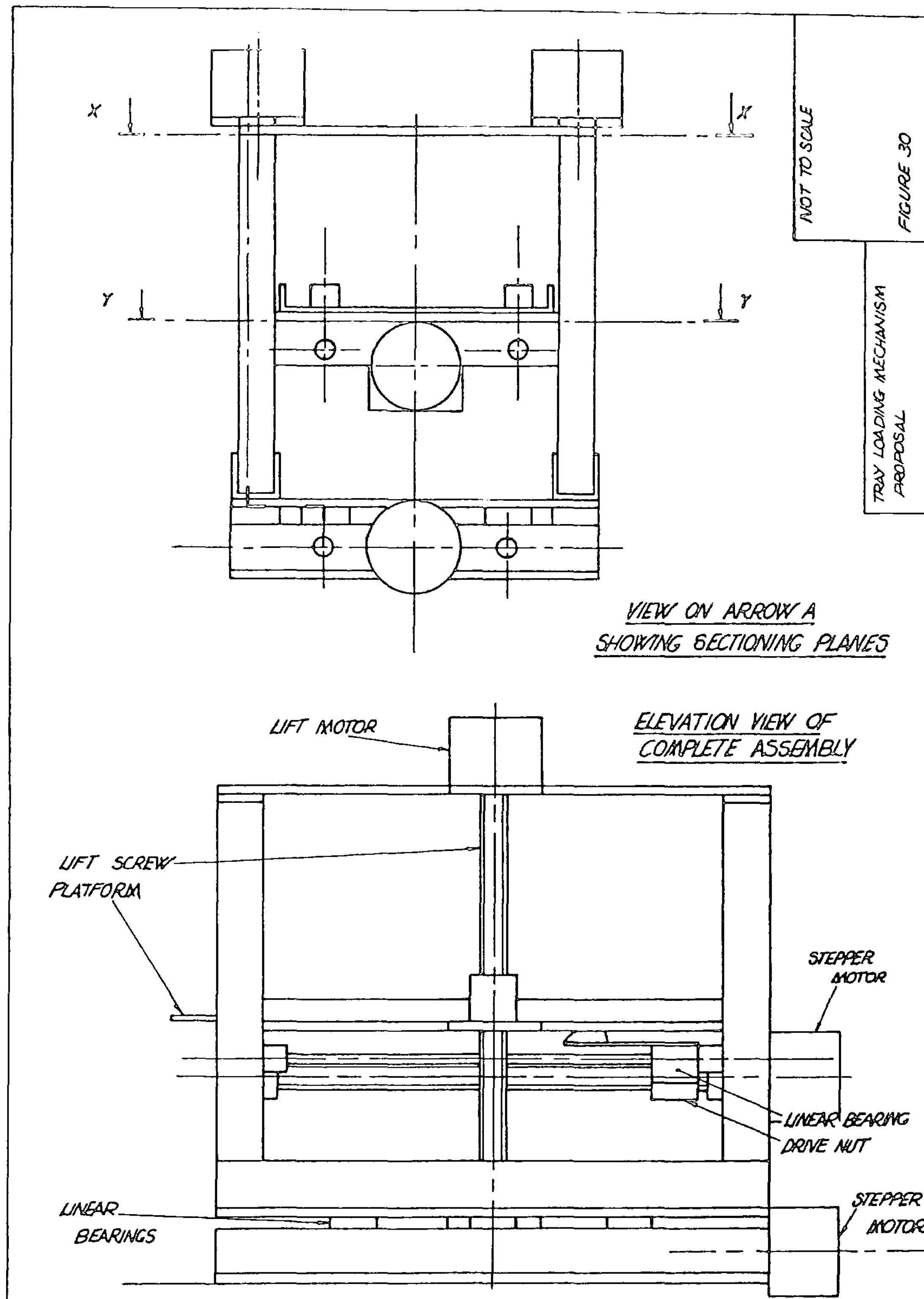
FIGURE 28b

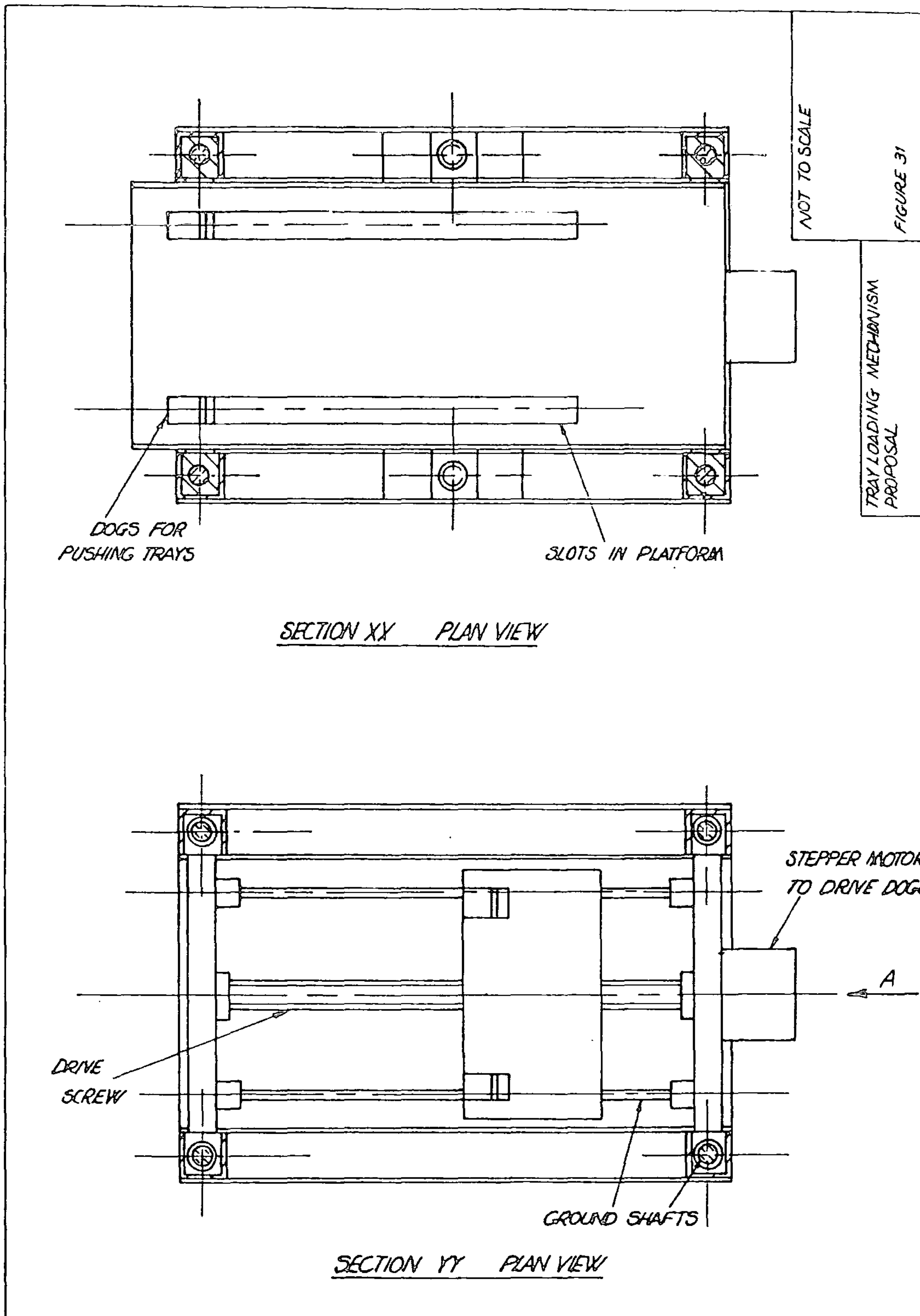


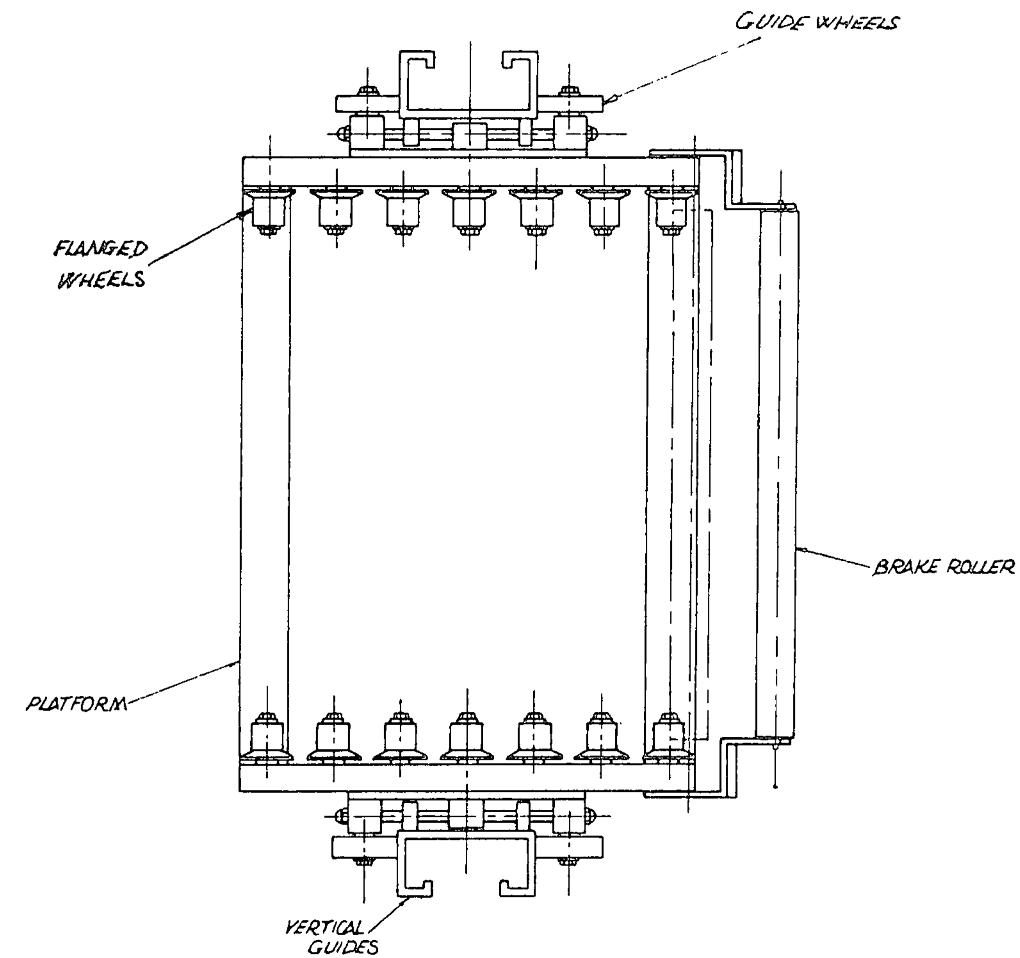
TRAY BRAKE - CLOSE UP
PLAN VIEW

SCALE 1:1

FIGURE 29


NOT TO SCALE
FIGURE 30
TRAY LOADING MECHANISM PROPOSAL
X
X
Y
Y
VIEW ON ARROW A
SHOWING SECTIONING PLANES
ELEVATION VIEW OF
COMPLETE ASSEMBLY
LIFT MOTOR
LIFT SCREW
PLATFORM
STEPPER
MOTOR
LINEAR BEARING
DRIVE NUT
LINEAR
BEARINGS
STEPPER
MOTOR

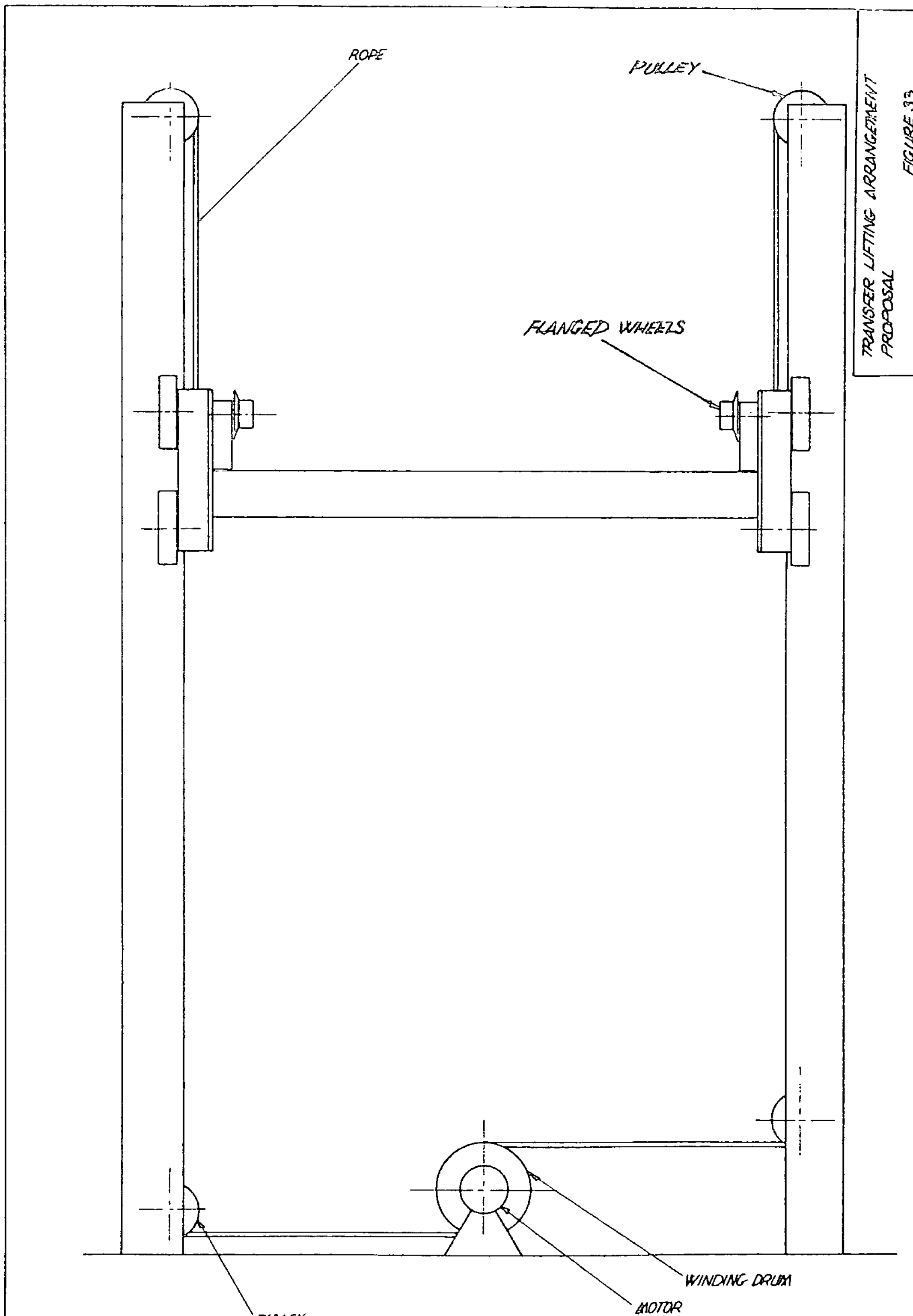

NOT TO SCALE
FIGURE 31
TRAY LOADING MECHANISM PROPOSAL
DOGS FOR PUSHING TRAYS
SLOTS IN PLATFORM
SECTION XX PLAN VIEW
STEPPER MOTOR TO DRIVE DOGS
A
DRIVE SCREW
GROUND SHAFTS
SECTION YY PLAN VIEW



TRAY PLATFORM PROPOSAL
PLAN VIEW

SCALE 1:4

FIGURE 32


ROPE
PULLEY
FLANGED WHEELS
WINDING DRUM
MOTOR
PULLEY
TRANSFER LIFTING ARRANGEMENT PROPOSAL
FIGURE 33

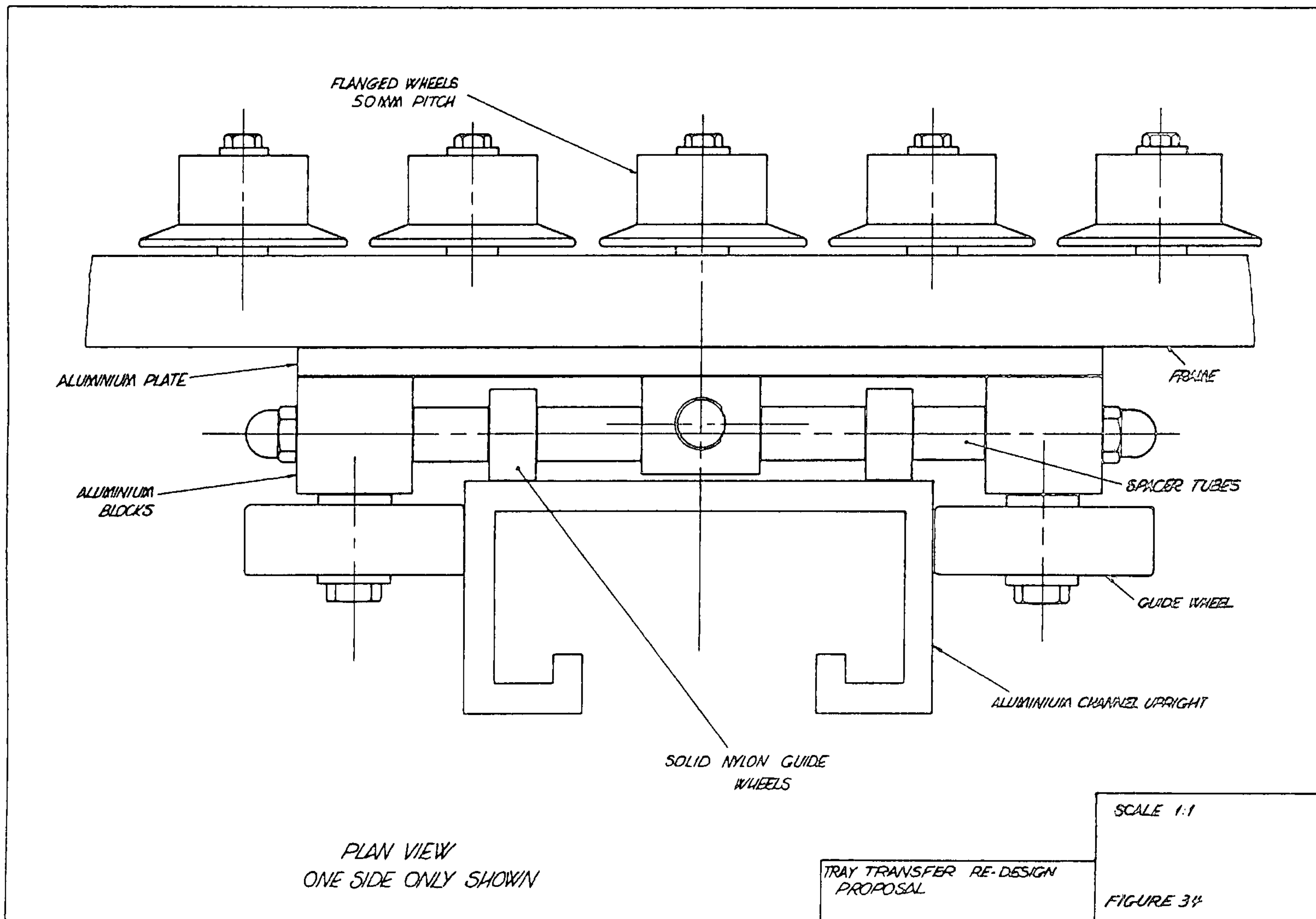
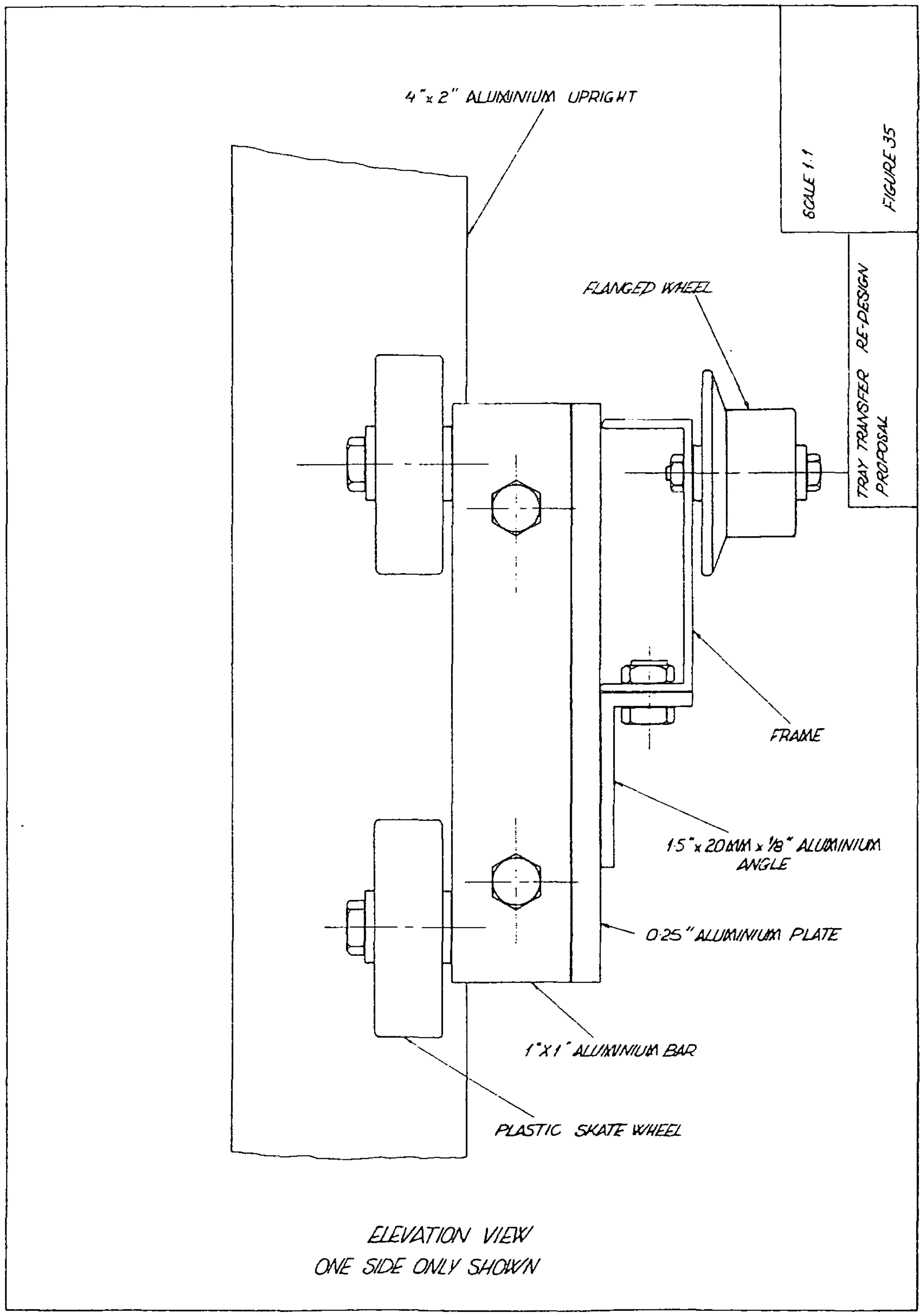
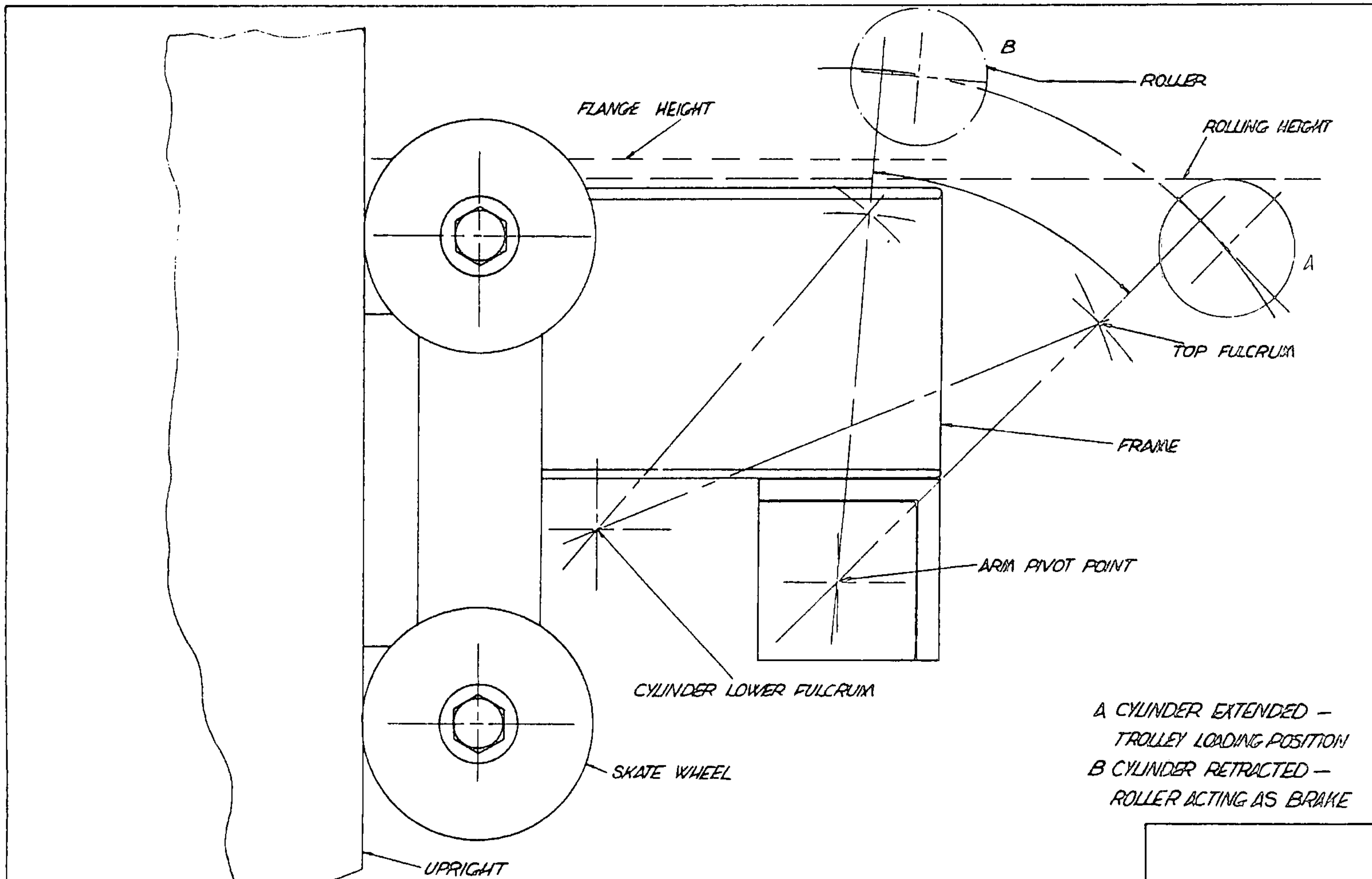

FLANGED WHEELS
50MM PITCH
ALUMINIUM PLATE
FRAME
ALUMINIUM BLOCKS
SPACER TUBES
GUIDE WHEEL
ALUMINIUM CHANNEL UPRIGHT
SOLID NYLON GUIDE WHEELS
PLAN VIEW
ONE SIDE ONLY SHOWN
TRAY TRANSFER RE-DESIGN PROPOSAL
SCALE 1:1

FIGURE 34

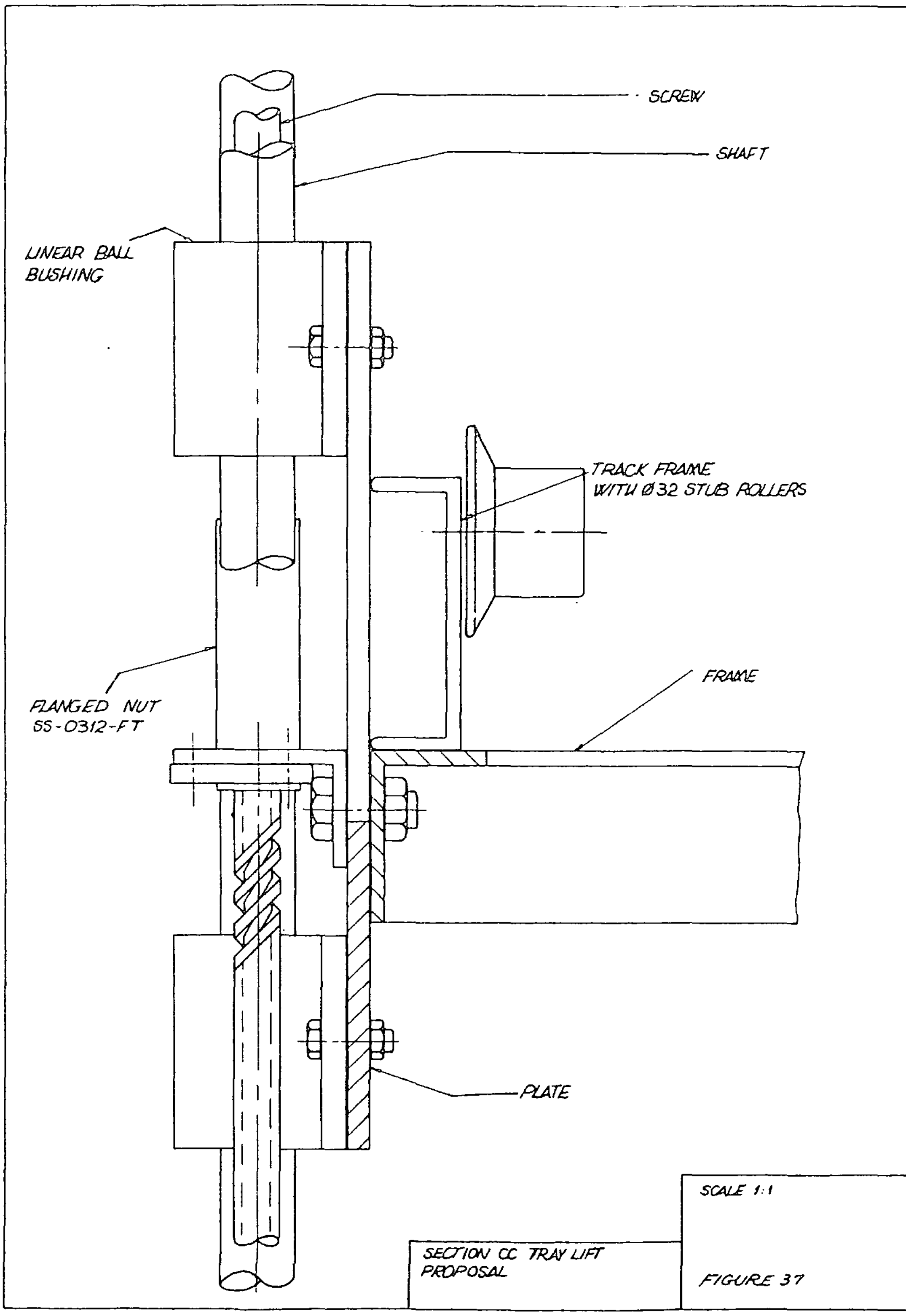


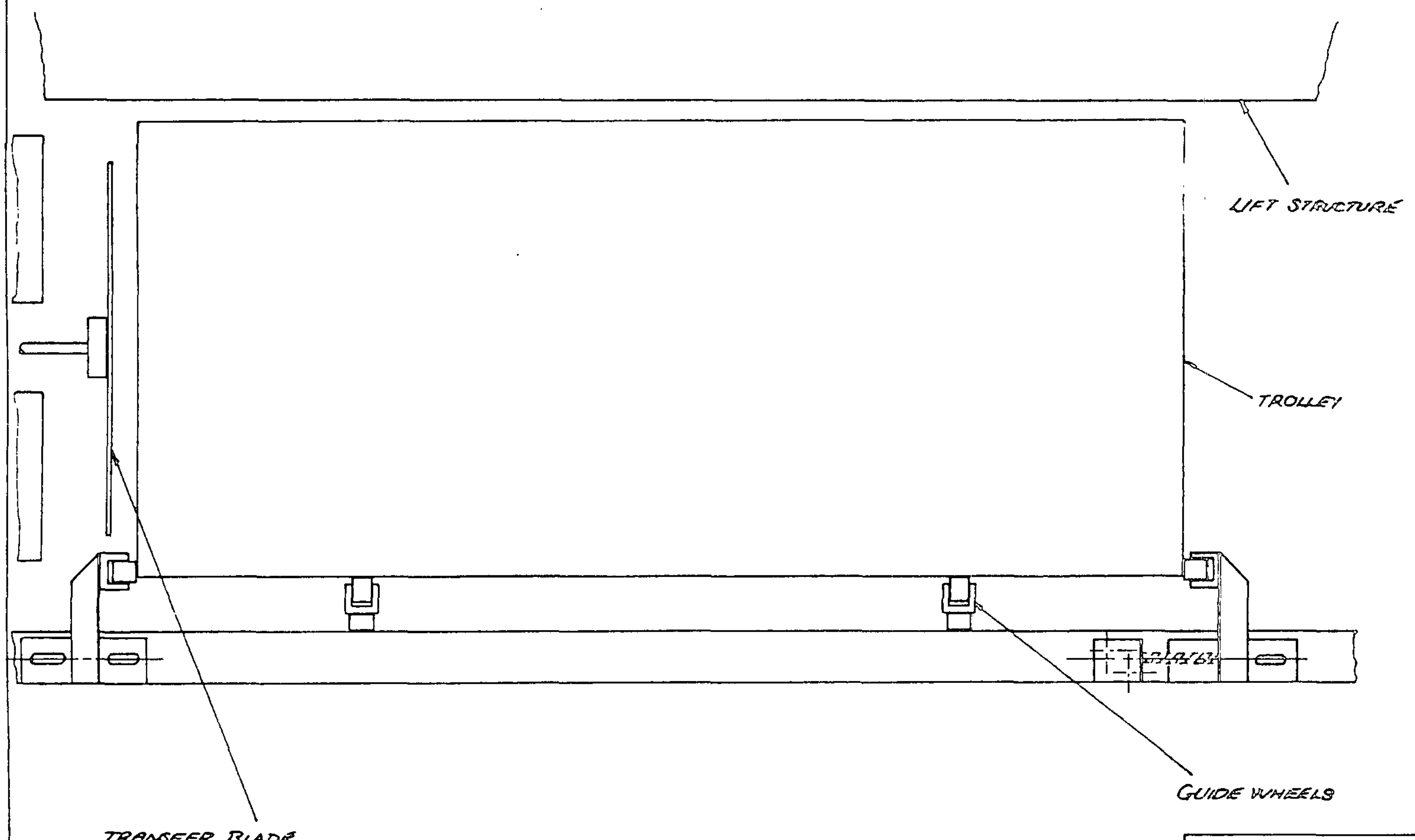
4" x 2" ALUMINIUM UPRIGHT
FLANGED WHEEL
FRAME
1.5" x 20MM x 1/8" ALUMINIUM ANGLE
0.25" ALUMINIUM PLATE
1" X 1" ALUMINIUM BAR
PLASTIC SKATE WHEEL
ELEVATION VIEW
ONE SIDE ONLY SHOWN
SCALE 1:1
FIGURE 35
TRAY TRANSFER RE-DESIGN PROPOSAL



BRAKE ROLLER DETAILS
PROPOSAL

SCALE 1:1
FIGURE 36

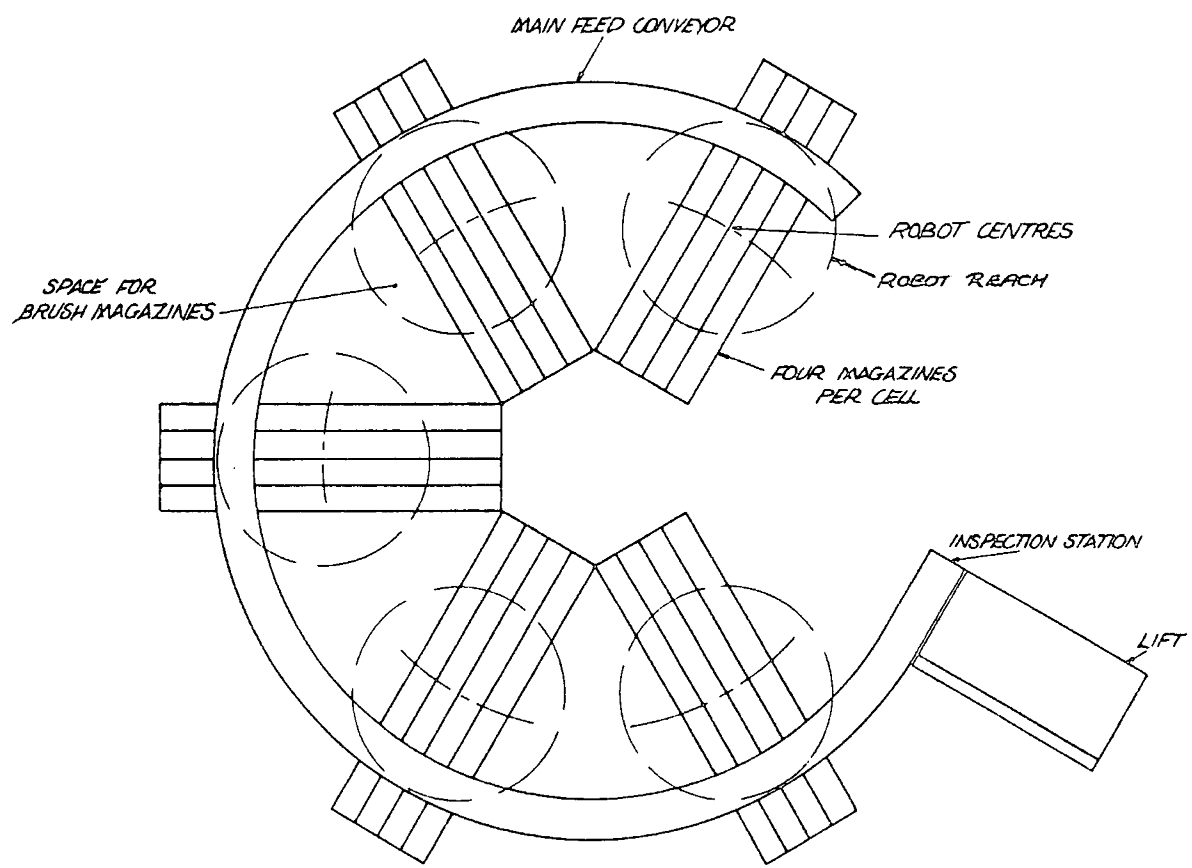

SCREW
SHAFT
LINEAR BALL
BUSHING
TRACK FRAME
WITH Ø32 STUB ROLLERS
FRAME
FLANGED NUT
SS-O312-FT
PLATE
SCALE 1:1
SECTION CC TRAY LIFT
PROPOSAL
FIGURE 37



TROLLEY CLAMP
PLAN VIEW

SCALE 1:4

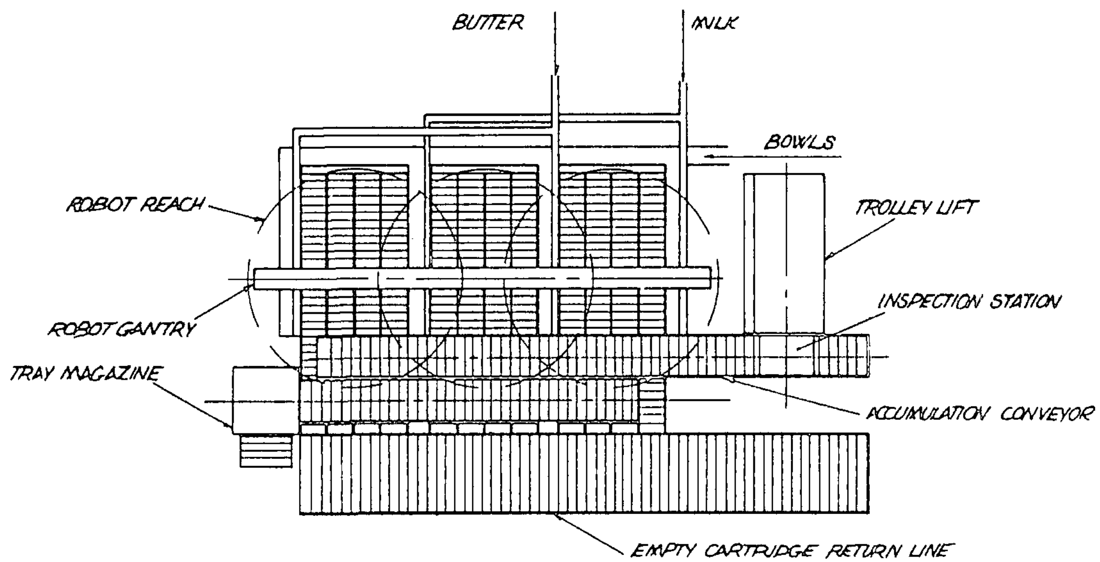
FIGURE 38



GENERAL LAYOUT
1ST SCHEME

SCALE 1:40

FIGURE 39



GENERAL LAYOUT
2ND SCHEME

SCALE 1:40
PLAN VIEW

FIGURE 40