5. INTRODUCTION TO THE LABORATORY: DESCRIPTION OF THE LABORATORY AND BASIC SCENARIO

5.1. System architecture

The structure of the Ethernet/IP network is depicted in Fig. 5.1. It contains five nodes, Aero Lift process control, computer and analog/digital controls (knobs, switches) and indicators. The main node is the CompactLogix L35E PLC controller made by the Allen-Bradley company. The other nodes are: POINT_IO, WAGO 750-341 I/O adapter, PowerFlex 40E inverter and PanelView Plus600 touch panel. All the nodes are connected via the Ethernet media channel to the Ethernet/IP industrial protocol. The host computer is used to configure all the elements of the network, program the PLC controller and analyze the Ethernet/IP packets transmitted over the TCP/IP or UDP protocols. An internet camera (Webcam) is used to generate additional packet traffic on the Ethernet network.

Each of the nodes in the network provides the following function:

- CompactLogix L35E PLC controller executing a control algorithms. This node receives the Ethernet packet containing the measurement data from the POINT_IO and WAGO 750-341 I/O adapter, generates a control value and then sends it (in the form of an Ethernet packet) to the PowerFlex 40E inverter.
- POINT_IO and WAGO 750-341 I/O adapter are directly connected to the Aero Lift process. They measure the position of the movable lift by utilizing proximity capacitance sensors. The signal from the sensors is connected to the digital input modules.
- PowerFlex 40E inverter provides the required power and adjusts the speed of the AC motor. The reference rotational speed signal is received as an Ethernet packet from the CompactLogix L35E PLC controller.
- PanelView Plus600 touch panel is not normally used in the project. However it can be used as an HMI (Human Machine Interface). Connection to a PLC controller can be made using either RSLinx or KEP OPC Server software.

All the nodes of the Ethernet/IP network were placed in a specially designed Allen-Bradley demo case. The main component of the Allen-Bradley demo case is the Compact Logix Controller 1769-L35E. The controller consists of the following elements:

- CPU (Central Processing Unit)– firmware revision 16.3,
- 15 MB internal memory,
- one RS232 serial port and one 100Mb/s EtherNet/IP port,
- compact Flash card socket,
- power supply Allen-Bradley 1769-PA2, input :120/240VAC, output: 24VDC,
- digital I/O module Allen-Bradley 1769-IQ6XOW4 (firmware revision 2.1 series B),
- analog I/O module Allen-Bradley 1769-IF4XOF2 (firmware revision 1.1 series A),
- terminal of the CompactBUS Allen-Bradley 1769-ERC.

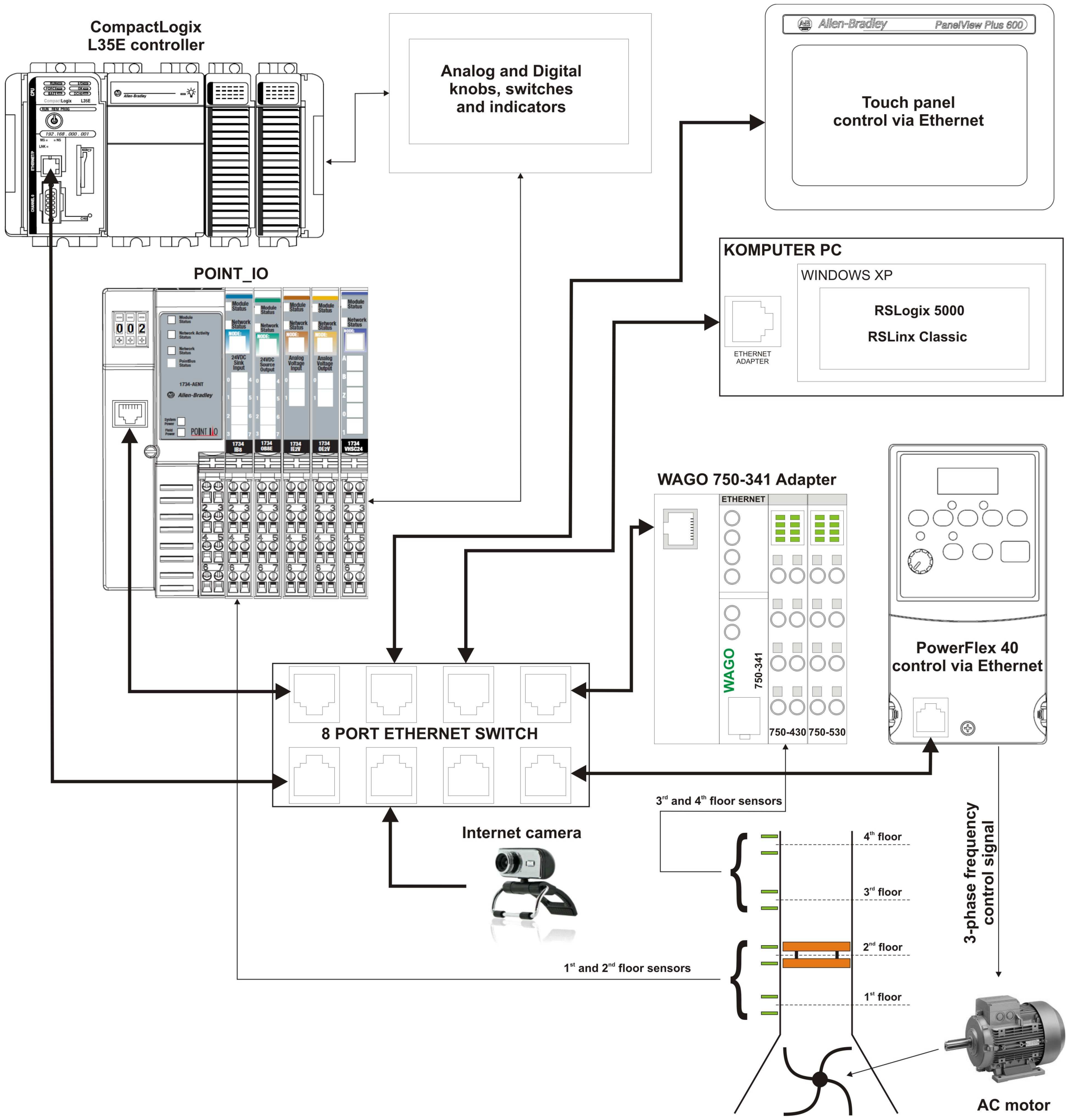


Fig. 5.1. Schematic diagram of the laboratory setup

The main parameters of the CompactLogix L35E local I/O modules are presented in Table 5.1. The 1769-L35E controller is designed for mid-range applications. It is equipped in the operating system with a pre-emptive multitasking system. This environment supports as many as 8 tasks, but only one can be continuous. A task can have as many as 32 separate programs with their own executable routines and program tags.

Table 5.1. The main parameters of the CompactLogix L35E local I/O modules

1756-ENBT	1769-IQ6XOW4	1769-IF4XOF2
• interface for a ControlLogix controller to communicate with other devices over an EtherNet/IP network, • adapter for 1756 I/O modules, • web server to provide diagnostic and status information, • communication via produced/consumed tags and MSG instructions.	• 6 digital inputs 24V DC (sinking/sourcing), operating voltage range 10 to 30 V, • 4 digital outputs 24V relay (AC/DC), operating voltage range 5 to 265V AC and 5 to 125V DC • I/O diagnostic LEDs.	• 4 analog inputs (differential or single-ended), analog normal operating ranges: voltage 0-10V, current 0-20 mA, resolution: 8-bits plus sign, response time: 5 ms/channel, • 2 analog outputs (single-ended), analog normal operating ranges: voltage 0-10V, current 0-20 mA, resolution: 8-bits plus sign, response speed: 0.3 (resistance, inductor), 3 ms (capacitance).

The 1734-AENT adapter can carry up to six I/O modules. They are mounted in a POINT_IO's chassis and communicate with the 1734-AENT adapter via internal bus. Basic parameters of the 1734-AENT and installed I/O modules are summarized in Table 5.2.

Table 5.2. Parameters of the distributed POINT_IO modules

1734-AENT	• Serves as a bridge between POINT I/O modules and the Ethernet/IP network, • Provides communication for *CompactLogix*, *ControlLogix* controllers (supports connections from multiple controllers simultaneously), • Communication via produced/consumed tags, • EtherNet/IP messages encapsulated within standard TCP/UDP/IP protocols, • Half/full duplex 10 Mbit or 100 Mbit operation (RJ-45, interfacing via category 5 rated twisted pair cable).
1734-IB8	• 8 digital inputs module: 24 V DC, sink, • Operating voltage range: 10…28.8 V DC. • Allows input filter time in the range of 0…63 ms.
1734-OB4E	• 4 digital outputs module: 24 V DC, source, • Output current rating max. 1 A/channel, • Outputs are not isolated, • Operating voltage range: 10…28.8 V DC.

1734-IE2V	• 2 analog inputs module. Operating ranges voltage: -10... +10 V. • Input resolution: 15-bits plus sign (–32,768...+32,767), • The module produces 6 bytes of input data and fault status data: 2-bytes data/channel, 1-byte status/channel, • Operates in unipolar or bipolar mode.
1734-OE2V	• 2 analog outputs module. Output voltage signal range: 0... +10 V or -10... +10 V, • Output resolution: 13-bits plus sign (–32,768...+32,767), • The module consumes 4 bytes of output data: 2-bytes/channel, • The module produces 2 bytes of fault status data: 1-byte/channel, • Operates in unipolar or bipolar mode.
1734-VHSC24	• Very High Speed Counter module: 24V, • Accepts feedback from an encoder (either single ended or differential), pulse generators, or mechanical limit switches at frequencies up to 1 MHz, • Allows filtering with four settings (50Hz, 500Hz, 5kHz or 50kHz).

The fieldbus coupler 750-341 accepts all the peripheral I/O modules in the WAGO-I/O-SYSTEM 750. When power is applied to the fieldbus coupler, it automatically detects all I/O modules connected to the coupler and creates a local process image. This can be a mixture of analog and digital modules. The process image is subdivided into an input and an output data area. The 750-341 coupler is able to send/receive process data via Ethernet and supports a series of network protocols. For the exchange of process data, the MODBUS TCP (UDP) and the Ethernet/IP protocols are available. However, the two communication protocols cannot be used together. Other protocols such as HTTP, BootP, DHCP, DNS, SNTP, FTP and SNMP are provided for the management and diagnosis of the system. The main parameters of the installed digital I/O modules are shown in Table 5.3.

Table 5.3. The I/O modules of the WAGO node

750-430	• 8-channel digital input module, DC 24 V, • Each input module has an RC noise rejection filter with a time constant of 3.0 ms, • The status of the input channels is indicated via status LEDs, • 1-conductor connection, high-side switching allowing direct connection to pnp-type digital sensors, • The process image of the module occupies 1-byte.
750-530	• 8-channel digital output module, DC 24 V 0.5 A, • The status of the input channels is indicated via status LEDs, • Short-circuit-protected, high-side switching, • The process image of the module occupies 1-byte.

The PanelView Plus 600 is an operator interface. It is equipped with a 5.5 inch display with touch screen. It works on Windows CE. The panel offers many possibilities for presenting data such as animations, trends and data collection. Visualization can be implemented using RSView

Studio environment. Communication with the panel uses the Ethernet interface. The data exchange between Ethernet/IP devices and PanelView uses the OPC client/server mechanism.

Allen-Bradley PowerFlex 40 AC drive is the smallest and most cost-effective member of the PowerFlex family of drives. The PowerFlex 40 is designed to be used for speed control in applications such as machine tools, fans, pumps and conveyors and material handling systems. The main features of the PowerFlex40 AC drive are:

- integral keypad for simple operation and programming,
- 4 digit display with 10 LED indicators for display of drive status,
- communication with PC using the RS-485 interface, Ethernet/IP (also DeviceNet, PROFIBUS DP, LonWorks and ControlNet interface are available),
- Autotune allows the user to take into account individual motor characteristics,
- Sensorless Vector Control provides exceptional speed regulation and very high levels of torque across the entire speed range of the drive,
- built-in PID cotroller,
- Timer, Counter, Basic Logic and StepLogic functions,
- built-in digital and analog I/O (2 analog inputs, 7 digital inputs (4 fully programmable), 1 analog output, 3 digital output),
- easy set-up over the network (RS NetWorx property).

The Ethernet/IP parameters assigned to the each node are shown in Table 5.4.

Table 5.4. Ethernet/IP parameters of the laboratory setup modules

	CompactLogix L35E	**1734-AENT**	**PanelView Plus 600**	**PowerFlex40**	**WAGO 750-341**
IP Address	192.168.1.1	192.168.1.2	192.168.1.3	192.168.1.5	192.168.1.182
Subnet Mask	255.255.255.0	255.255.255.0	255.255.255.0	255.255.255.0	255.255.255.0
Gateway IP Address	none	none	none	none	none

5.2. Aerolift Overview

The aero-lift (AL) system is designed to carry out several tasks. The test-rig contains the blower based on a 3-phase drive steered by the inverter, 2 pipes for vertical motion of the cart and 8 discrete sensors to measure the cart’s position (see Fig. 5.2).

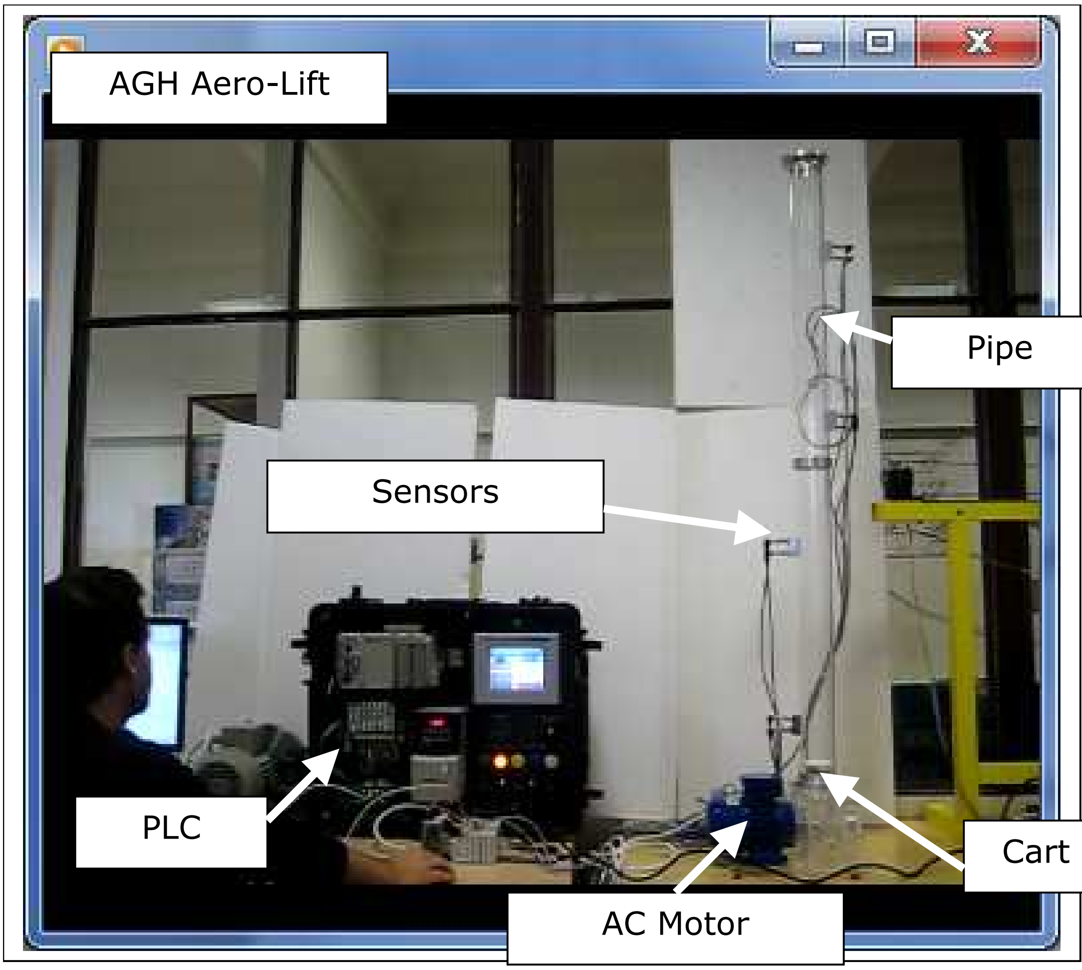


Fig. 5.2. Aero-Lift - laboratory test-rig

The system was designed to fulfill requirements of distributed drive control and digital measurements. The pipes are mounted in a stackable form to obtain 4 floor building model. Each floor is equipped with 2 sensors to detect the cart's position. The cart contains 2 plates that stabilize the motion in the pipe and prevent flipping. These plates are used for sensing purposes too. The schematic diagram of the system and floor section is presented in Fig. 5.3 a and b respectively.

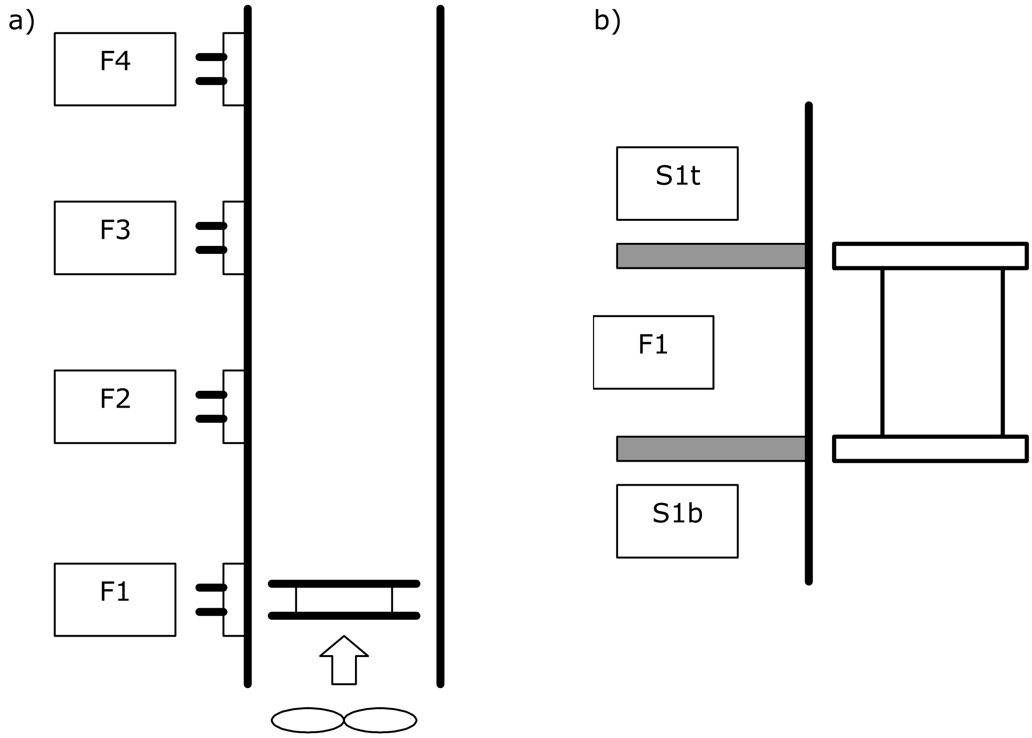


Fig. 5.3. Aero-Lift test rig: a) system overview, b) floor configuration

These two sensors are used to position the cart at the desired floor and to detect the cart's motion. The latter is carried out by monitoring the sensor states. The controller can thus provide an appropriate control strategy.

High level control can be realized as automata that have 8 inputs and one output (as four values) with a steady control adjusted for the desired level.

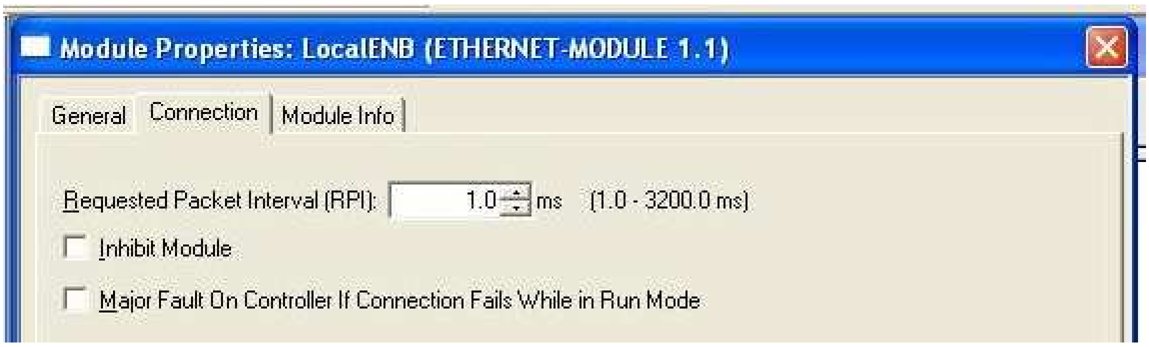
The direct dynamics controller must be much more complex due to the cart dynamics, non-linearity of the lifting force that depends on the cart position, its mass, and blower characteristics. Its performance must be investigated in the identification experiments.

This controller can operate on the measurement available from sensors or can use an internal observer to estimate the cart's position.

Because one of the aims of the CoNeT project is to diagnose and observe the consequences of lost data, jitter or delays in data collection, the direct measurement of the cart sensors will be used. Therefore, the digital sensors are connected to 2 devices that can handle digital signals and transmit their states via the network to the host PLC. These devices: the distributed I/O and the WAGO controller, are available via the network addresses X.X.X.2 and X.X.X.182 respectively. Both of them can be configured with a variable scan time from 2-750ms from the

PLC side. Fig. 5.4 shows the user interface that allows the user to configure the Ethernet module and the Requested Packet Interval (RPI), and schedule for digital data scan with the specified task type set to Periodic and by defining Period, Priority and Watchdog. The PLC and system programmer are able to manually adjust the appropriate settings to fulfill the control system requirements. This means that the system user can test the influence of the sensing frequency for system controllability. Moreover, the sensed data are transmitted via the network and some latency in the transmission can occur. This is observable as a jitter in the data delivery and can be diagnosed via the appropriate software. To diagnose these effects the WireShark application can be used.

a)



b)

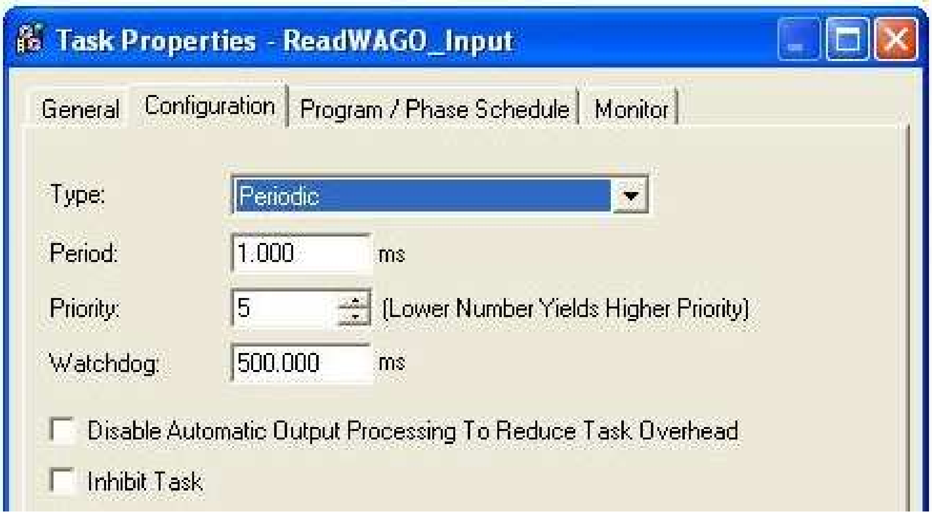


Fig. 5.3. Aero-Lift test rig: a) system overview, b) floor configuration

The aero lift is an example of a dynamic system that is sensitive to sampling time and latency in data transmission. With this set-up a number of consequences caused by inaccurate settings for Ethernet modules and I/O blocks can be observed. Extra protection algorithms can be implemented to guarantee the safe operation of the lift.

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