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The Design of Improved Automatic Operation Control of Indonesian Low- Speed Wind Tunnel Based on Programmable Logic Controller and Human Machine Interface

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A B S T R A C T

In the application of the Indonesian Low-Speed Tunnel (ILST), the control of wind tunnel operations can determine the validity of the data and the number of tests achieved daily. The current operation control mechanism is still done manually and separately with one series of measurements for one test model configuration, inefficient human resources, acquisition of data that can be different, and the cost of using electric power is quite expensive. Therefore, this research and development activity proposes a wind tunnel automatic operation control system that integrates several plant facilities and ILST data acquisition based on Human Machine Interface (HMI) with the Waterfall method, using SCADA software and PLC. This aims to improve wind tunnel operation in one measurement series for multiple test model configurations with high data acquisition accuracy, faster and easier operation to reduce operating costs. This automatic operation control can increase operation time two times faster and 61% cheaper than manual operation. The design results will be used at the implementation stage in aerodynamic model testing.

INTRODUCTION

A wind tunnel is a tubular apparatus or tunnel with a cross-section that has a man-made wind to blow through at a certain speed [1]. Wind tunnel is an experimental tool used in aerodynamics research, in which air is forced to travel at a regulated speed, in order to study the aerodynamic flow effects of existing objects [2][3]. Wind tunnels are mostly used in aerodynamic products that need to be tested before being applied in daily life practice.

The construction of a wind tunnel is accompanied by the development of aircraft to date for testing the configuration of aircraft taking off, flying straight, and landing, which then also develops its use in non-aircraft tests including sea transportation and land transportation (such as trains and cars) to determine forces and moments of aerodynamics, finding ways to reduce the power required to drive vehicles on the highway at a certain speed, interactions between the road and others to obtain a prototype car [4] with small drag [5], small thrust, agile, and stable to get fuel efficient car. Likewise, for constructing high-rise buildings and long-span bridges capable of withstanding wind forces, knowledge of strength and structure is required for simulation rules prior to construction. Wind is an important consideration in structural design, and bridges frequently have complex geometries and are located in complex terrain that can be exposed to high wind loads [6].

The application of wind tunnels is necessary to reduce the risk to human safety and vital objects that can occur, even though the mathematical calculations have been carried out by using computation [7]. Indonesia, as an archipelagic country from Sabang to Merauke, is up to 5,245 km which are separated by the sea with a population of more than 250 million people; it requires adequate air, sea, and land transportation facilities both produced by itself and other countries and long span bridges [8] as well as buildings [9] in urban areas is therefore a prospect for aerodynamics research and the use of wind tunnels in Indonesia.

One of the well-known research facilities for aerodynamic testing in Indonesia is the Indonesian Low Speed Tunnel (ILST) (as shown in Figure 1). It is an aerodynamic science testing facility operated by the Laboratory of Aeroelastic Aerodynamics and Aeroacoustics under the auspices of the National Research and Innovation Agency (LA3-BRIN). ILST developed to supports research and development of the aerodynamics and aerodynamics industry [10] in Indonesia. The ILST-type wind tunnel is an atmospheric closed circuit with a test section area of 3 x 4 meters

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and a length of 10 meters. since February 1987, it has been operating at speeds of up to 80 meters/second [2].

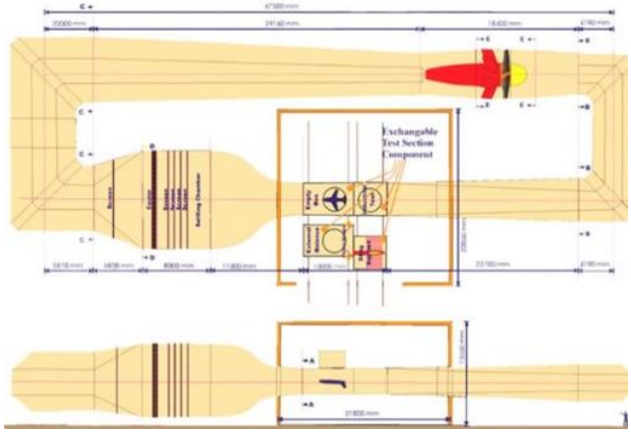

Figure 1. Indonesian Low Speed Tunnel (ILST)

Wind tunnel operation is the simultaneous operation of generating facilities in accordance with their functions [11], which is supported by the ILST-generating facility which is equipped with a local Programmable Logic Controller (PLC) and a central PLC as follows:

- Sting Support Test Section.
- External Balance Test Section.
  Sting Support Test Section (Figure 2a) and External Balance [5] (Figure 2b) used for measuring aerodynamic forces and moments in testing aircraft models.
- Empty Box Test Section (Figure 2d).
- Industrial Test Section
  Empty Box Test Section (Figure 2d) and Industrial Test Section (Figure 2e) are used to measure aerodynamic forces and moments in testing non-aircraft test models such as tall buildings, long-span bridges, and ships.
- Fan Drives
  Controlling and producing airflow [12] in the wind tunnel up to speeds of 80 meters/second by controlling the rotating speed of the motor [11] DC 2.1 Mega Watt, which is installed with eight blades, as shown in Figure 4, through a DC drive.
- Cooling System
  Air temperature controller in wind tunnel-ILST.
- Compress Air System (CAS)
  High-pressure air generator up to 60 bar.
- Air Distribution System (ADS)
  To flow high-pressure air to the Mass flow Control system.
- Mass flow Control System (MCS)
  To circulate high-pressure air according to mass, CAS, ADS, and MCS are needed to test an airplane test model with an engine [13] (Power On).
- Mechanism of Traversing
  Used as a setting place for measuring instruments in the test section.
- Central PLC as a monitor control center for all local PLC activities placed in each ILST facility plant, data acquisition and HMI-based automatic operation control (Figure 2c)
- Data Acquisition
  Data Acquisition [1] [14], a separate unit from the ILST control system, is used for measurement data capture in the ILST-wind tunnel test (Figure 3).

(a) (b)

(c)

(d) (e)

Figure 2. (a) PLC Sting Support test section, (b) PLC External Balance test section, (c) Central PLC ILST, (d) PLC Empty Box test section, and (e) PLC Industrial test section

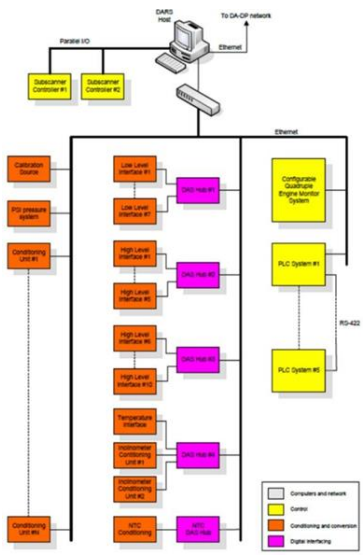

Figure 3. Data Acquisition Devices

Currently, the ILST wind tunnel operations are still carried out manually by operating the plant facilities and data acquisition units by several operators separately with different procedures and time intervals for data collection and different measurement data acquisition, which causes inefficiency in the use of human resources. One-series measurements are only made for one model configuration due to the model settings are done manually.

Therefore, this research proposes an HMI-based automatic control system through a monitor display by communicating the Programmable Logic Controller (PLC) installed in the plant facility in a different place from the Supervisory Control and Data Acquisition (SCADA) through serial communication [15] Thus, with the current technological demands, it is required faster and easier to create a new plant control model, integrate 5 plant facilities and ILST data acquisition (Figure 8) to reduce operators, operating costs, precise aerodynamic data measurement results, and increase the number of test achievements per day in testing operations in the ILST-wind tunnel. Meanwhile, the use of PLC and SCADA so far in the industry is to control 1 or 2 plants [16] [17].

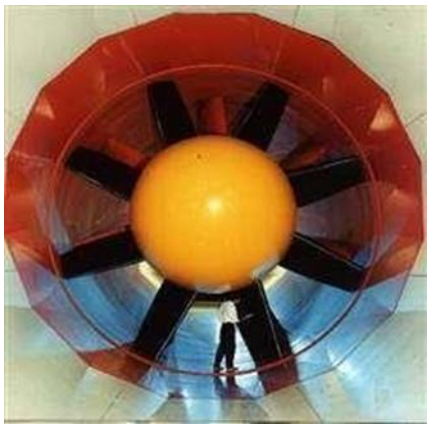

Figure 4. DC Motors with 8 Blades

Therefore, this research aims to design an HMI-based ILST automatic operation control system integrated with data acquisition in the measurement process that allows in 1 measurement series to test several test model configurations. This is to improve the current wind tunnel operation in terms of daily testing achievements with good data validity, reduce operational costs, and describe the design stages, the results of design activities, and optimal design recommendations.

METHOD

Wind Tunnel Test

Testing in the wind tunnel [18] [19] is taken in serial measurements from 100 to 10,000 times, this due to the needs of service users from the standard of aerodynamics industry [20]. This test is carried out to measuring the aerodynamic forces and moments from the response balance connected to the aerodynamic model placed in the test section flowing with air at a specified speed to obtain good and validated aerodynamic data. In order to obtain validated data for the calibration, it is necessary to conditioning and setting the deflection of the test model components during changes in alpha (angle of attack) and or beta (sideslip) angles in a good position, stable air velocity and air temperature in the measurement process. This should be carried out by operating the ILST facility plant simultaneously with high safety standard procedures.

ILST Facility Plant Control System

Each ILST facility plant installed in a different place is equipped with a control system for open-loop and closed-loop control functions [21], which is operated locally through the Remote Operating Panel (ROP) and remotely from the control room via Desk Operating Panel (DOP) using pushbutton and 7-segment display. The controller device used by the ILST facility plant is based on a Programmable Logic Controller (PLC). The employed PLC is LS Glofa GM-4 (second generation) type after being updated in 2012 with a control system configuration, as shown in Figure 5. Meanwhile, the the feature system of DOP installed in the ILST control room is shown in Figure 6.

Problem Formulation

1. Since 1987, ILST has operated manually with its plant facilities through an operator panel with push buttons and a 7-segment display, using PLC SattControl SC-15, SC-31, and SC-60 technology from the 1980s that was made in Sweden [22].
2. In 1998, a supplier in the Netherlands stated that technical support and spare parts ended in 2000.
3. The ILST control system [2] of the ILST-plant facility was updated from PLC SattControl to PLC LS GM-4 with processor technology in the 2000s for manual plant operations through the operator panel with push buttons and 7-segment displays.
4. In 2018, a supplier in Indonesia stated that PLC LS GM-4 spare parts were no longer being produced.
5. Updating the control system currently used by ILST needs to be carried out immediately for the continuity of ILST operations.
6. Therefore, the improvement of the ILST facility control system and plant operation capabilities are required to support testing and reduce operating costs [23].

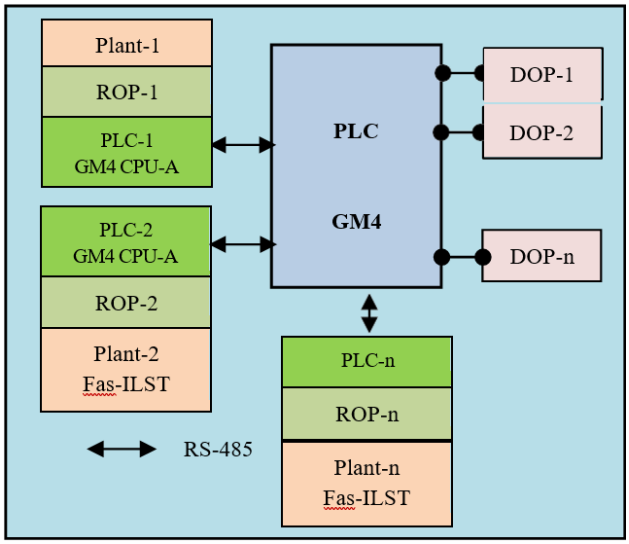

Figure 5. Control System Configuration-ILST

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Figure 6. Desk Operating Panel-ILST

Second Level Heading

The waterfall model [24][25] (Figure 7) is employed due to the equipment specifications are quite clear, and this model is regularly used in software development applications with the following manner stages:

1. Requirements: Collect and analyze information to obtain software requirements specifications that suit the needs and limitations of wind tunnel operations.
2. Design: Hardware and software systems design define the overall system architecture and test it.
3. Implementation: making application programs, testing and integration iterations, and function testing, used is still in the testing phase.
4. Verification: The system created in the previous stage is verified, and carried out integration, also system testing to meet the requirements. Partially or fully, the system has met the requirements.
5. Maintenance: software that is produced, used, and carried out maintenance. Maintenance includes fixing errors that can occur.

It should be noted that all above the System Problem Formulation in this study was directly identified by the researchers in the field (ILST lab facilities).

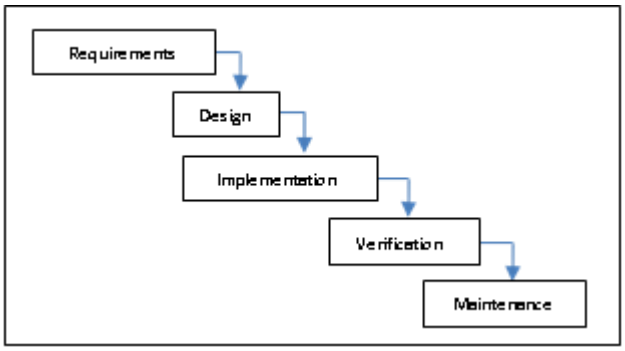

Figure 7. Waterfall Model [26]

Needs Analysis

According to the stages of the waterfall model [26] above, a requirements analysis is then carried out as follows:

1. Currently, ILST wind tunnel operations are still carried out manually. Plant facility operations and separate data acquisition units with measurement data acquisition can be different, wherein one series of measurements is carried out for 1 test model configuration.
2. Faster, easier, integrated, automatic HMI-based ILST wind tunnel operation control is required with precision measurement data acquisition.
3. Work procedures for plant facilities and data acquisition-ILST work procedures.
4. Procedures for wind tunnel-ILST operation and safety system operation-ILST.
5. Model control is needed to set the control plane angle of the test model components as a new facility plant.
6. Work integration of several plant facilities and data acquisition-ILST.
7. It can increase the number of tests per day, in one series of measurements can measure several test model configurations.
8. Design of plant facility control and HMI-based automatic data acquisition.
9. Programming HMI with SCADA and PLC software.
10. HMI integration of operation control and plant PLC program.
11. Function test of plant facility operation control and ILST operation control.

System Design

The second stage of the waterfall model is the design stage. In this study is refer to the design of the control system [27][28] HMI-based wind tunnel-ILST operation by creating an HMI using SCADA software and PLC. It is referring to the design as in Figures 8 and 9. Starting with the data retrieval of the current plant PLC program used to create the ILST facility plant operation control HMI, integration of plant operation and data acquisition operation and ILST operation control was carried out as follows:

Third Level Heading

In order to be able to operate an ILST-facility plant, an ILST-facility plant operation control or Operator Tunnel Control (OTC) is automatically created, and a new device that covers all ILST-facility plants.

OTC can monitor and control each ILST-facility plant through the HMI display [29][30][31] on a computer monitor that is communicated with the PLC [32], as shown in Figures 16a and 19b, installed on each ILST facility plant. The OTC plant facility is made to resemble the desk operating panel-ILST and can be functioned according to the working mechanism used in the measurement operation in testing the aerodynamic model at ILST.

a. OTC External Balance
   The external balance test section is operated manually and automatically through an HMI-based OTC external balance. With the Ready on signal, the plant is ready to be used in the measurement process by monitoring the operation of the alpha, beta, and light mechanisms with set On/Off switches according to their operation order.
b. OTC Data Acquisition
   HMI-based automatic OTC Data Acquisition-ILST work, integrated with the OTC plant to carry out monitoring

control of measurement data acquisition operations on tests in the wind tunnel according to the sequence.

c. OTC Industrial
Industrial test section work that can be operated manually and automatically via HMI-based Industrial OTC. With the Ready on signal, the plant is ready to be used for control monitoring of operations according to the work mechanism and sequence.

d. OTC Cooling System
The cooling system for manual and automatic operation through the HMI-based OTC Cooling System for monitoring control of the operation of the P-901/2 heat exchanger pump and cooling water pump 1 and 2, K-901 Low or K-901 High and K-902 Low or K-902 High.

e. OTC Models Control
Building OTC Model Control [33][34] based on HMI to activate servo work for setting deflection of control field components of test models, such as: Rudder, Flap, Aileron, and Elevator automatically, by inputting data and setting On/Off switches according to the sequence of operations.

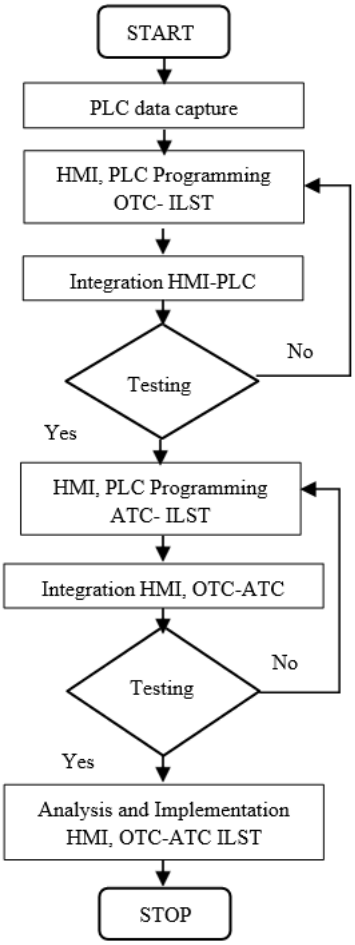

Figure 8. The LIST Operation Control HMI Design Flowchart

ILST Operations Control

ILST operation control based on HMI [35] or Automatic Tunnel Control (ATC) with a configuration as shown in Figure 10 is operation control for the measurement process by automatically integrating OTC plant facilities, OTC data acquisition, and OTC model control. With this ideal integration, the expected time can be obtained. Operation is two times faster, where in one series of measurements, it is possible to measure for several test model configurations with safe operating limits of air temperature in wind tunnels and fan drive motors.

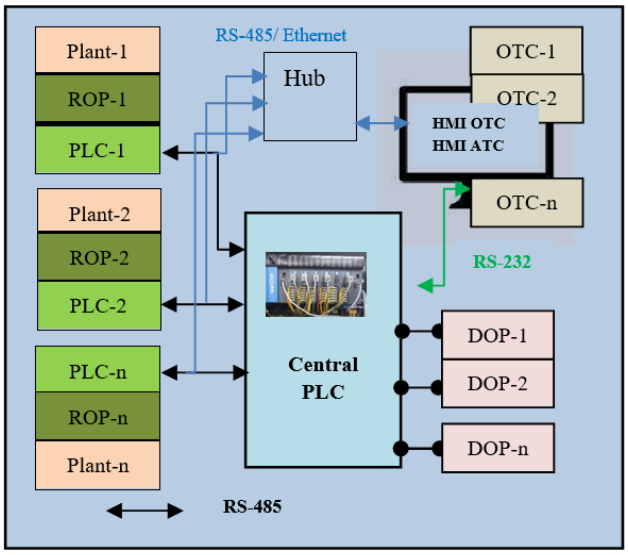

Figure 9. ILST Operation Control Configuration Design.

a. ATC Aeronautical Test
ATC Aeronautical Test is to control and monitors the measurement process in aircraft model testing (Figure 16c), by integrating plant facilities, OTC model control, OTC Cooling system, OTC External Balance, OTC Industrial, OTC Fan Drive, and OTC data acquisition with the configuration (Figure 10) and security systems through ILST circuits and external balance vibration sensors, wind tunnel temperature and fan drive motors. Operation by activating the looping measurement process as shown in Figure 12, according to the test model configuration with alpha, beta, or variation mechanism in the planned test.

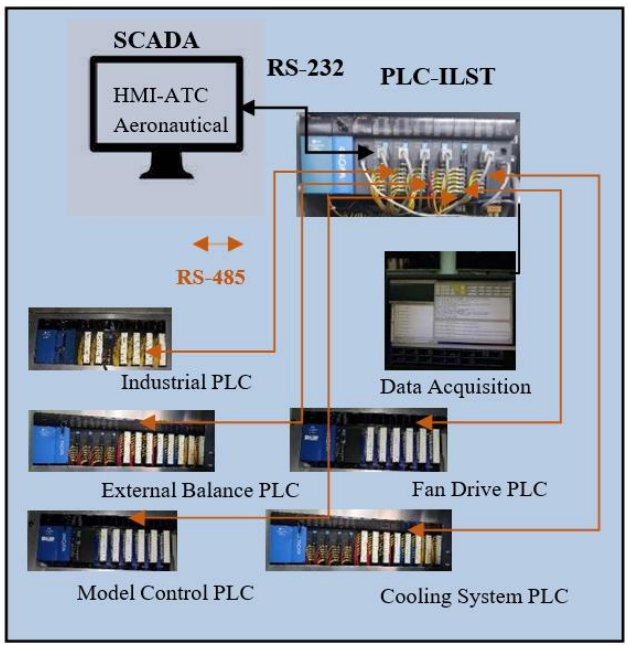

Figure 10. ATC Aeronautical Configuration Design

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b. ATC Non-Aeronautical Test
ATC Non-Aeronautical Test is to control and monitor the measurement process for non-aircraft models by integrating the OTC model control plant facilities, OTC Cooling system, OTC External Balance, OTC Industrial, OTC Fan Drive, and OTC data acquisition with its security system. Operations by activating the measurement process loop according to the configuration of the test model and the beta mechanism in the planned test.

Data Collection and Analysis

Data collection is carried out by measuring the duration of the setpoint setting time and travel time from the setpoint value to the actual value manually as follows:

1. Setpoint setting time is required for the plant to start moving the actual value towards the setpoint value.
   a. Measurement of beta angle setpoint setting in Industrial test section table-1, setpoint setting time for 6 - 9 seconds for one setpoint through DOP and 4 - 7 seconds through ATC step by step and 3 seconds with multi-step ATC.
   b. Measurement of Alpha and Beta setpoint settings in the External balance test section obtained the same time as the industrial.
2. Travel time is the time required for the plant control monitor to move the actual value to the setpoint value entered according to the test requirements. Measurements were taken during testing at ILST through the DOP manually.
   a. Measurement of the time required to reach the air velocity from 0 m/s to the speed used during the test (70 m/s) for the Fan Drive plant for 300 seconds and to reduce the air velocity from 70 m/s to 0 m/s for 420 seconds.
   b. Measurement of the time required to reach the required alpha angle from angle 0 to angle -10º and then to angle 15º with a step of 1º, where the movement for every 1º takes 10 seconds, on the External balance plant.
   c. Measurement of the time required to reach the required Rudder model angle setting from an angle of 0º to 40º for an average of 10 seconds, with a small servo control on the plant control model. For manual model setting it takes 600 seconds.
   d. Measurement of the time required for retrieval of test data from an alpha angle of -10º to15º with a step of 1º, where the retrieval of each measurement point normally takes 4 seconds.

Data Analysis

The testing process in the wind tunnel manually for one configuration of the test model consists of the setting time of the model angle setpoint in the plant Table-1, the travel time of the setpoint value to the actual value Table-3, and the interface time between the angle setting operator and the data retrieval operator.

From Table 1, the setpoint setting time of measurements for the nine measuring points through the DOP total setpoint setting time: 74 seconds, through ATC step by step for 46 seconds, and only 13 seconds with multi-step ATC. In the measurement process of 4 test model configurations with 36 measuring points per 1 configuration. During testing in the wind tunnel using the ILST automatic operation control design based on HMI (ATC) multi-step, the total average measurement time is close to the data in table-4 = 3,256 seconds or one configuration = 814 seconds with a deviation of 150 to 200 seconds for four configurations as setpoint setting time. The use of ATC can reduce the setpoint setting time and eliminate the interface time between manual operators, and does not interfere with the operation through the DOP which is the choice of automatic or manual operation.

Table 1. Manual Operation using DOP

No	Manual Operation using DOP	Time (sec)
1	Setting model 10 minutes	600
2	Set airspeed 0 -70m/s	300
3	Set Ext. Balance Alpha 0, -10º sd.15º/1º =36º@10s	360
4	Fetch data, Alpha -10º sd. 15º/1º = 26º@4s	104
5	Set Ext. Balance Alpha 15º sd.0º, 16º@10s	160
6	Set airspeed 70 - 0 m/s	420
•	Total travel time 1 model configuration	1,944
•	Setpoint setting time =36º@ 6 - 9s (7s)	252
•	Operator interface time =36º@ 3s	108
•	Total real measurement time of 1 model configuration	2,304
•	Total measurement time of 4 model configurations	7,776
•	Total real measurement time of 4 manual model configurations	9,216

Operation Control Security System-ILST

Wind tunnel operations are supported by manual and automatic high-security systems to maintain human safety, test models, wind tunnels and plant facilities that focus on fan drives, while the security systems are as follows:

1. Emergency Stop on the plant, 4 test sections, and fan drive.
2. Vibration sensor on the model control plant, sting support, and external balance exceed 2G.
3. Temperature in the plant fan drives the cooling system.
4. Wind tunnel circuit doors closed.
5. Fan drive motor blade rotation protection.

Programmable Logic Controller (PLC) and SCADA (Supervisory Control and Data Acquisition)

PLC [36] is a control device used in ILST facility plants programmed to control functions of both open and closed loops [37]. According to the plant function, which is communicated with the control center for setting ratio of 200 to 1000
Input/Output, the program is stored in non-volatile with battery backup. The LS Glofa GM-4 PLC is used at each facility plant to support the ILST-wind tunnel operation, which can be operated both locally and remotely from the ILST-control room.
SCADA combines ILST facility plants monitored and controlled from separate locations at a certain distance. Within that operation, a Human Machine Interface (HMI) was developed [38] that combines telemetry and data acquisition systems. The collection of measurement information is sent to the control

center then data and control are displayed on several SCADA display operators consisting of a Master Terminal Unit (MTU) as a control center. Remote Terminal Unit (RTU)/PLC controls the plant with field devices connected via a communication interface, as shown in Figure 11. In this study, the SCADA data is then expandability by the XGT InfoU.

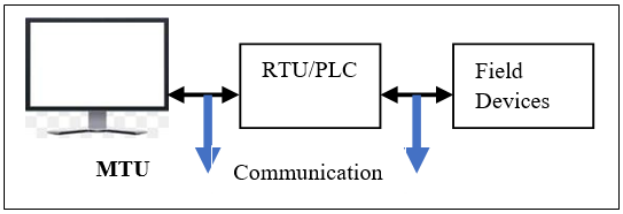

Figure 11. SCADA Stand-alone system

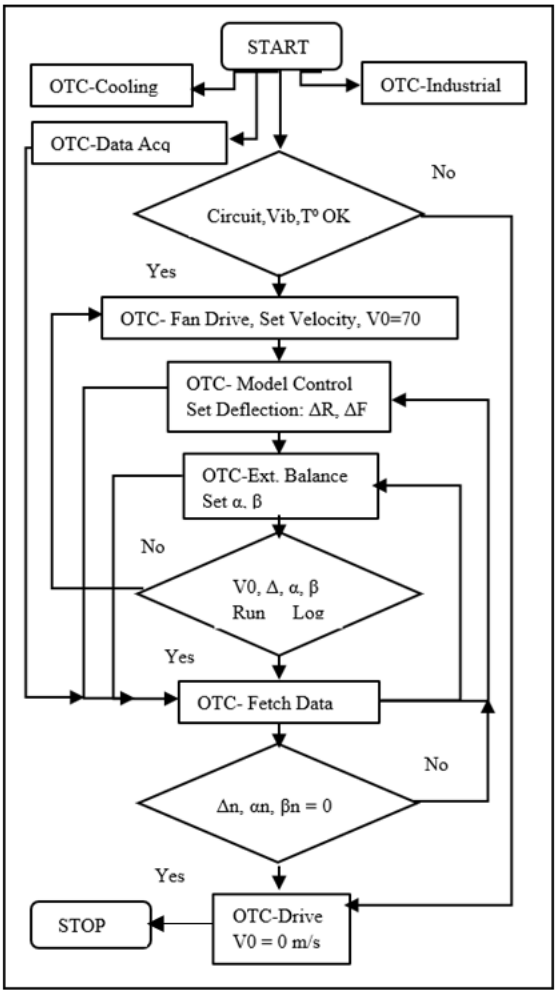

Figure 12. HMI ATC Aeronautical Test flowchart

RESULTS AND DISCUSSION

The research results are the realization of plant facility operation control (OTC) to control ILST facility plants manually and automatically and ILST operation control to control various ILST facility plants and integrated the data acquisition for carrying out measurements in wind tunnels (ATC). OTC and ATC are checked through testing to determine whether the work of the developed system works well and under the design and meets the needs analysis.

OTC Functional Test

The plant operation control function test at the ILST facility is meant to check the functioning of the plant in accordance with its function through the desk operating panel and OTC, as shown in Figure 13 a and b. For checking the work of the Industrial test section lighting is shown in Figure 14a. Meanwhile, for checking the performance of the external balance test section lighting and the work of the cooling system is shown Figure 14b.

Table 1. Operation setting time of beta angle deflection OTC Industrial

No	Beta Angle Control		Actual HMI	Actual DOP	DA
A	**Set via ODP step by step**	**Time**			
1	Setting SP : - 20.00°	3 secs	-20.02	-20.02	-20.02
2	Setting SP : - 15.00°	6 secs	-15.01	-15.01	-15.01
3	Setting SP : - 10.00°	5 secs	-10.02	-10.02	-10.02
4	Setting SP : - 05.00	6 secs	-5.01	-5.01	-5.01
5	Setting SP : 00,00	5 secs	00.00	00.00	00.00
6	Setting SP : 05.00	5 secs	5.01	5.01	5.01
7	Setting SP : 10.00	6 secs	10.01	10.01	10.01
8	Setting SP : 15.00	5 secs	15.01	15.01	15.01
9	Setting SP : 20.00	6 secs	20.02	20.02	20.02
	Total time of Setting Beta 9 points			SP	
	Push button Enter Time			1 sec	
	Push button On time			1 sec	
	Push button Off time			1 sec	
	Total Response time -20°/20°			**74 secs**	
B	**Set via ATC step by step**	**Time**	**Actual HMI**	**Actual DOP**	**DA**
1	Setting SP : - 20.00°	3 secs	-20.02	-20.02	-20.02
2	Setting SP : - 15.00°	3 secs	-15.01	-15.01	-15.01
3	Setting SP : - 10.00°	3 secs	-10.02	-10.02	-10.02
4	Setting SP : - 05.00	2 secs	-5.01	-5.01	-5.01
5	Setting SP : 00,00	1 sec	00.00	00.00	00.00
6	Setting SP : 05.00	1 sec	5.01	5.01	5.01
7	Setting SP : 10.00	2 secs	10.01	10.01	10.01
8	Setting SP : 15.00	2 secs	15.01	15.01	15.01
9	Setting SP : 20.00	2 secs	20.02	20.02	20.02
	Beta Setting total time		SP		
	pop up OK time		1 sec		
	Push button On time		1 sec		
	Push button Off time		1 sec		
	Total Response time -20°/20°		**46 secs**		
C	**Sett via ATC, multi step**	**Time**	**Actual HMI**	**Actual DOP**	**DA**
	Setting SP : -20.00/20.00/5.00 9 points	2 secs	-20.02 /20.02 /5.00	-20.02 /20.02 /5.00	-20.02 /20.02 /5.00
	START button push time		1 sec		
	Interface time of 9 points @1sec		9 secs		
	Push button Off time		1 sec		
	Total Response time -20°/20°		**13 secs**		

The OTC Industrial function test aims to check the beta angle setting work, the system configuration was set in step by step and multi-step as shown in Figure 16a, and this to compare the response time between operations through DOP and OTC. This data can be obtained from the DOP display, OTC, and acquisition data, as in Table 1, by ignoring the work process and travel time of beta angle setting due to the operation with DOP and OTC is the same condition. The setting is with ramprate-4, every 1° is

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taken for 4 seconds. The beta angle setting time for the same number of angles manually step by step through OTC (46 seconds) is faster than through DOP (74 seconds). It can be further accelerated automatically by multi-step through OTC (13 seconds).

Figure 13a and b. Functional Test OTC Industrial

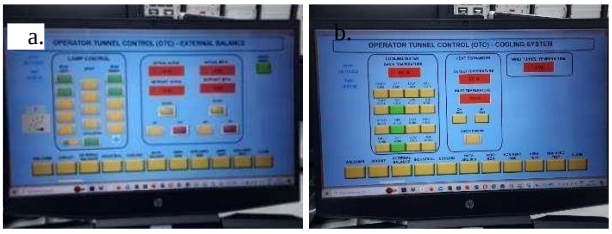

Figure 14. a. Functional HMI Test Ext Balance, b. Cooling Function test.

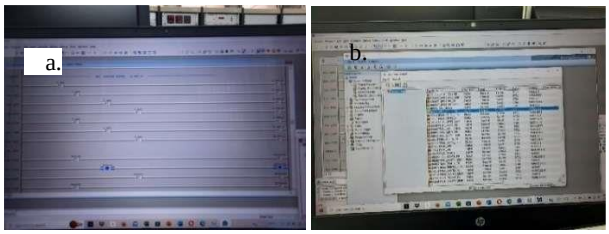

Figure 15. a. Programming, b. OTC and ATC - PLC integration

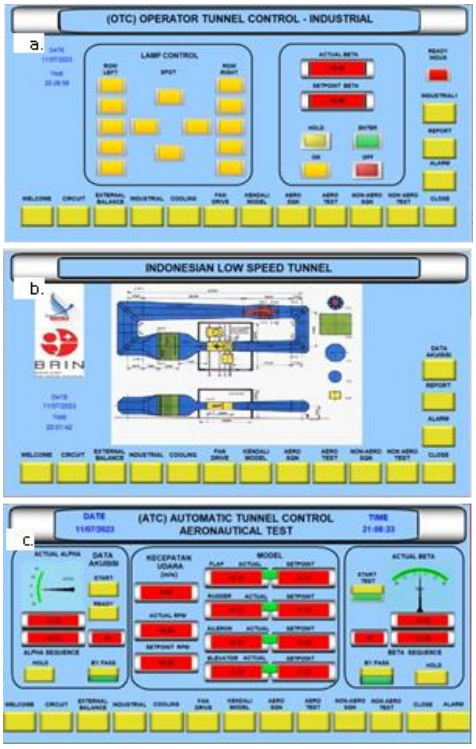

Figure 16. (a) Functional Test HMI OTC Industrial, (b) HMI Operations Control ILST, and (c) HMI ATC Aeronautical Test

ATC Functional Test

Aeronautical ATC HMI function test to check the functioning of the Aeronautical ATC Test in accordance with its function, as shown in Figure 16c, with operating steps according to Table 2. This can enable the work of several OTC plants and data acquisition in the measurement process automatically.

Table 2. Operation steps of ATC Aeronautical Test

No	Monitor Control Object	In HMI	Out HMI
1	Setting and check test models		
2	Check circuit-ILST, TM - Circuit	On	On
3	*OTC Industrial active sets*	On	On
4	*Set active OTC Cooling System*	On	On
5	*Active set of OTC Data Acquisition*	On	On
6	***Set active OTC Models Control, Set ΔR:1***	On	On
7	OTC Fan drive, Set V0:70 m/s	On	On
8	*Set active OTC* Ext.Bal Alpha,Beta:An:α,Bn:1	On	On
9	V0=70, An:α, Bn:1, Circuit:1	On	On
10	Start-DA ~ Ready-DA	On	On
11	*Set active OTC* Ext.Bal Alpha,Beta: An:α,Bn:2	On	On
12	V0=70, An:2, Bn:β, Circuit:1	On	On
13	Start-DA ~ Ready-DA	On	On
14	*Set active OTC* Ext.Bal Alpha,Beta: An:α,Bn:3	On	On
15	V0=70,An:2,Bn:β,Circuit:1	On	On
16	Start-DA ~ Ready-DA	On	On
17	***Set OTC Models Control, Set ΔR:2***	On	On
18	Set Ext.Balance Alpha,Beta: An:α, Bn:1	On	On
19	V0=70,An:α,Bn:1,Circuit:1	On	On
20	Start-DA ~ Ready-DA	On	On
21	Set Ext.Balance Alpha,Beta: An:α, Bn:2	On	On
22	V0=70,An:α,Bn:2,Circuit:1	On	On
23	Start-DA ~ Ready-DA	On	On
24	Set Ext.Balance Alpha,Beta: An:α, Bn:3	On	On
25	V0=70,An:α,Bn:3,Circuit:1	On	On
26	Start-DA ~ Ready-DA	On	On
27	Set Ext.Balance Alpha, Beta:An:1,Bn: β	On	On
28	V0=70,An:1,Bn:β, Circuit:1	On	On
29	Start-DA ~ Ready-DA	On	On
30	Set Ext.Balance Alpha,Beta:An:2,Bn:β	On	On
31	V0=70,An:2,Bn:β, Circuit:1	On	On
32	Start-DA ~ Ready-DA	On	On
33	Set Ext.Balance Alpha,Beta: An:3, Bn:β	On	On
34	V0=70,An:2,Bn:β, Circuit:1	On	On
35	Start-DA ~ Ready-DA	On	On
36	***Set OTC Models Control, Set ΔR:1***	On	On
37	Set Ext.Balance Alpha,Beta: An:3, Bn:β	On	On
38	V0=70,An:3,Bn:β, Circuit:1	On	On
39	Start-DA ~ Ready-DA	On	On
40	Set Ext.Balance Alpha,Beta: An:2, Bn:β	On	On
41	V0=70,An:2,Bn:β, Circuit:1	On	On
42	Start-DA ~ Ready-DA	On	On
43	Set Ext.Balance Alpha,Beta: An:1, Bn:β	On	On
44	V0=70,An:1,Bn:β, Circuit:1	On	On
45	Start-DA ~ Ready-DA	On	On
46	***Set OTC Models Control, Set MK:0***	On	On
47	Set Ext.Balance Alpha,Beta: An:0, Bn:0	On	On
48	V0=0,An:0, Bn:0, Circuit:1	On	On
49	Start-DA ~ Ready-DA	On	On
50	Close: non-active OTC Fandrive, Cooling	Off	Off
51	Close: non-active Data Acquisition, Industrial	Off	Off
52	Close: non-active OTC External balance	Off	Off
53	Close: non-active OTC Models Control	Off	Off

Comparison of ILST operation control HMI designs

As the ILST operation control configuration design in Figure 9, there are 2 configurations with 2 different communication interfaces [39] as follows:

1. Configuration is with RS-232.
   a. The farthest distance of ILST operating HMI from PLC is 15meters.
   b. ILST operation HMI can replace DOP work.
   c. Maximum data rate of 20 Kbit per second.
   d. Central PLC is still maintained, and the control system is stable; replacing a new control system (PLC) is relatively expensive.
   e. ILST operation is with HMI and DOP.
2. Configuration is with RS-485/Ethernet.
   a. The farthest distance of the HMI from the PLC is up to 100meters.
   b. ILST operation HMI can replace DOP work.
   c. Higher speed than RS-232, up to 100 Mbit per second.
   d. Central PLC can be removed, for replacing a new controlsystem is relatively cheap.
   e. ILST operation is without DOP, fully with HMI.

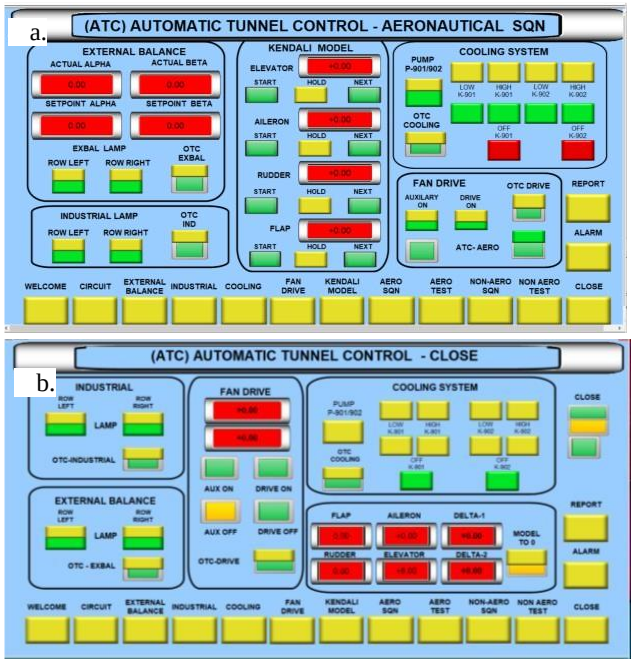

Figure 17. (a) HMI ATC Aeronautical Sequence and (b) HMI ATC Close

Ease of operation HMI ILST operation control

According to the needs analysis, the ILST operation control is easy to operate with three stages of operation as follows:

1. Stage-1: Preparations that can be operated manually through each OTC, OTC external balance, Industrial, fan drive, model control, and cooling system or automatically through ATC Aeronautical and non-aeronautical sequences as in Figure 17a.
2. Stage-2: After stage-1 is completed, measurement operations can be carried out automatically through the ATC Aeronautical Test shown in Figure 16c by pressing the Test Start button to start measurements for variations in alpha and/or beta angles with variations in the angle of the test model component, Flap, Rudder, Aileron and Elevator and others.
3. Step-3: Deactivate the plant facility automatically by deactivating each OTC used when the measurement activity is completed by pressing the Close button on ATC Close, as shown in Figure 17b.

Table 3. Manual Operation Time

No	Manual Operation using DOP	Time
A.1	Set Rudder -10º, setting model 10 minutes	600
2	Set airspeed 0 -70m/s	300
3	Set Ext. Balance Alpha 0, -10º sd.15º/1º =36º@10s	360
4	Fetch data, Alpha -10º sd. 15º/1º = 26º@4s	104
5	Set Ext. Balance Alpha 15º sd.0º, 16º@10s	160
6	Set airspeed 70 - 0 m/s	420
B.1	Setting model, Rudder - 5º, setting model 10 minutes	600
2	Set airspeed 0 -70m/s	300
3	Set Ext. Balance Alpha 0, -10º to15º/1º	360
4	Fetch data, -10º to 15º/step1º	104
5	Alpha angle settings 15º to 0º	160
6	Set airspeed 0 m/s	420
C.1	Setting model, Rudder 5º, 10 minutes	600
2	Set airspeed 70m/s	300
3	Set Ext. Balance Alpha 0, -10º sd.15º/1º	360
4	Fetch data, -10º to 15º/step1º	104
5	Alpha angle settings 15º to 0º	160
6	Set airspeed 0 m/s	420
D.1	Setting model, Rudder 10º, 10 minutes	600
2	Set airspeed 70m/s	300
3	Sett Ext. Balance Alpha -10º to 15º/1º	360
4	Fetch data, -10º sd. 15º/step 1º	104
5	Setting Ext. Balance Alpha Angle 15º to 0º	160
6	Set airspeed 0 m/s	420
	Total operating time for 4 test model configurations (seconds)	7.776
	Electricity consumption without model setting time = 5,316 seconds, assuming IDR 1,500 per kWh, At V0 : 70m/s the electric power consumption is 1MW/h	Rp 2,215,000
	Operating time + drive for 1 configuration (seconds)	1.929
	4 Operator preparation 5 Operator measurement	

Comparison of Cost and Operating Time of Manual and ATC

From the aerodynamic model measurement process in the ILST wind tunnel that has been carried out manually for 4 test model configurations, operating time data for each ILST facility plant is obtained compared to the ATC design with the same number of measurement points as in Tables 3 and 4. The time results obtained = 7.776 secs / 3.256 secs = 2.388 times faster, and the cost ratio of fan drive electricity = Rp 1,356,667 / Rp 2,215,000 = 0.612 or 61% cheaper. It would be more effective if measurements were made for 100 to 10,000 run test model configurations.

Operation using ATC

Operations using ATC, as shown in Table 4, carry out the sequence of measurement processes as shown in Figure 12, with looping and time pauses that can be adjusted according to

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measurement needs with a 200-millisecond scan program. These operations can speed up the measurement time compared to manually, at model setting, alpha and beta angle setting, data retrieval, and pause between settings at the same time in the looping process.

Table 4. Operating Hours with ATC

No	Operation using ATC	Time
1	Set airspeed 0–70m/s	300
2	*Setting model, Rudder -10º*	10
3	Alpha angle settings 0, -10º to 15º/1º = 36º@10s	360
4	Fetch data, Alpha -10º to 15º/1º = 26º@4s	104
5	Alpha angle settings 15º to 0º, 16º@10s	160
6	*Set model, angle Rudder -5º*	10
7	Alpha angle settings -10º to 15º/1º	360
8	Fetch data, -10º to 15º/1º	104
9	Alpha angle settings,15º to 0º,16º@10s	160
10	*Setting model, Rudder 5º*	10
11	Alpha angle settings -10º to 15º/1º	360
12	Fetch data, -10º to 15º/1º	104
13	Alpha angle settings 0º	160
14	*Setting model, Rudder 10º*	10
15	Alpha angle settings -10º to 15º/1º	360
16	Fetch data, -10º to 15º/1º	104
17	Alpha angle settings 0º	160
18	Set airspeed 0 m/s	420
	Total operating time for 4 test model configurations (seconds)	3.256
	Electricity consumption with model setting time = 3,256 seconds, assuming IDR 1,500 per kWh,	Rp. 1.356.667
	Operating time + drive/4 1 configuration (seconds)	814
	NB. Drive = set airspeed Setting the alpha/beta angle and taking manual data 3 – 5 seconds and with ATC 200 ms – 1 s 3 Operator preparation 3 Operator measurement	

The Role of the OTC Control Model

The role of the OTC control model is to establish the OTC control model as a new plant facility for automatic test model setup and use in operation through ATC as shown in Figure 16c and Table 4. In addition, the control OTC model has an important role in improving the operation control capability of ILST to be fully automated, increasing the operation time in one measurement series can be achieved measurements for multiple test model configurations and increase the number of test results per day.

Use of Fan Drives

The use of the OTC fan drive operated through the ATC is more efficient. After all, it can reduce electricity costs because it is operated at the beginning and end of the measurement with the temperature limitations of the fan drive motor and the air temperature in the wind tunnel, as shown in Figure 16c and Table 4.

Data Acquisition in ATC

Retrieval of measurement data in ATC operation can be adjusted for the time and duration of data collection after setting the alpha or beta angle according to measurement needs when the test model is stable, the airflow is laminar, and others relevant measurement.

CONCLUSIONS

Based on the results of this study, the function test and analysis of ILST operation control based on Human Machine Interface can improve current manual operations, as evidenced by its ability to operate four or more test model configurations in one measurement series at a speed of 2.3 times faster and easier. In addition, it can reduce the number of operators and operating costs. The measurement data is more precise due to the same timing conditions and measurement methods, with 61% cheaper electrical power consumption costs only for the fan drive. The operating speed with RS-232 communication is sufficient for ILST data acquisition response time, as an alternative configuration with ethernet network communication can eliminate the central PLC for cheaper control system updates. Operational OTC can be used as a replacement or backup unit for the Desk Operator panel. ATC and OTC can be used as an alternative to the Central PLC. This research can be helpful as a reference in updating the control system and controlling ILST operations. Further research can be continued for automatic operation control for testing aircraft test models with engines (Power on).

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NOMENCLATURE

ILST Indonesian Low Speed Tunnel HMI Human Machine Interface
SCADA Supervisory Control and Data Acquisition PLC Programmable Logic Controller
OTC Operator Tunnel Control ATC Automatic Tunnel Control
DOP Desk Operating Panel ROP Remote Operating Panel
Alpha angle, angle of attack or pitch, angle of the model to the wind direction
Beta angle yaw or heading angle

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