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Date: 20-Feb-2020

CORRIGENDUM/ADDENDUM

Tender No. NAL/PUR/CAD/322/19-Z
Tender ID: 2020_CSIR_43799_1 Dated 19-Feb-2020

In continuation of CSIR-National Aerospace Laboratories Tender No. NAL/PUR/CAD/322/19-Z Dated 19-Feb-2020 for **"Procurement of 3-axis Control Loading System along with the Mechanical Design and Fabrication of frame for use in a flight simulation**, kindly refer **"Modified Chapter–4"** before submission of bid.

Other clauses of the bidding document remain unchanged.

21-2-2020

Controller of Stores & Purchase
For and on behalf of CSIR

Chapter 4

Specifications and Allied Technical Details

3-axis control loading System along with the mechanical design and fabrication of frame

4.1 End Use: To simulate control stick, yoke and pedal forces on the Saras Mk2 Flight Simulator

4.2 Detailed Specifications

4.2.1 General Information

National Aerospace Laboratories (NAL), Bangalore is involved in the design and development of civil transport aircraft SARAS Mk2. To support the Avionics and FCS testing activity as well as pilot familiarization, Fixed Base Training Simulator (FBTS) is being setup. SARAS Mk2 will be certified to meet the following statutory requirements:

FAR Part 23: Airworthiness standards - Transport category
FAR Part 91: Air Traffic and General operating rules
FAR Part 121: Operating requirements - Transport category aircraft

This Request For Quotation (RFQ) specifically relates to the supply of **aircraft specific control loading system** for the FBTS. The control loading system is required for three axes, namely the pitch axis, roll axis and rudder pedals. Based on the selection of control loading motors, cradle and linkages have to be designed and fabricated for SARAS Mk2 flight simulator control loading system as per the detail/specifications provided in section 4.2.3.

4.2.2 Control Loading System Specification

Figures 4.2.2.1-4.2.2.3 provides detailed schematics of the reversible Primary Control System (PFCS) of SARAS Mk2. The SARAS Mk2 PFCS has an autopilot, which is interfaced in parallel to the reversible cable and linkages. The autopilot is designed to trip when the pilot generates sufficient override force. The various gearing ratios and forces on the system are given in Tables 4.2.2.1 through 4.2.2.10. **The values mentioned in Tables 4.2.2.1-4.2.2.10 and details presented in Figures 4.2.2.1-4.2.2.3 are likely to be modified during the technical discussion stage.**

Rack mounted CPU architecture for the inner loop of the control loader will be preferred. Windows operating system will be preferred for the reference Model Development / support software. The flight dynamic model of SARAS Mk2 will be executed in RTOS. Ethernet will be preferred for communication between the Control Loader Computer and Flight Dynamic Model. Suitable interface software to be provided for communication between the Control Loader Computer and Flight Dynamic Model.

The control loading actuators transfer forces and moments through linkages to the primary flight controls.

The vendor is requested to quote for both:

- SARAS Mk2 Flight Simulator Control loading system. The itemized costing shall be provided for control loading motors, control force measurement, software development, tuning support and training
- Design and fabrication of Cradle and linkages

as part of a turnkey control loading system solution with the highest fidelity of simulation. Modular generic frames, which allow incremental addition of seat shakers, quick change or re-configurability, will be preferred. The linkages must be designed for high stiffness, minimal friction and optimal gearing.

Final acceptance of the control loading system will be based on the demonstration of functioning of the control loader as per NAL requirements measured at the location of the pilot grip / rudder pedal by the vendor.

The vendor must also provide a schedule and detailed breakdown of activities. This schedule must incorporate two reviews, one by an internal committee consisting of experts from **NAL** and another by the supplier of CLS motors. A visit to the aircraft or simulator will also be arranged on request.

Table 4.2.2.1. Autopilot override forces

Attribute Actuator	Surface Hinge moment (in * lb)	Pilot Override (lb)
Elevator(150in.lb)	450	37.5
Aileron(150in.lb)	787.5 1050	21.15
Rudder(150in.lb)	8382	49.834

Table 4.2.2.2. Maximum and Minimum Permissible Pilot Forces/Moments

	Max. Force or Torque	Min. Force or Torque
Aileron Wheel	64.1*D	40D
Elevator Wheel	256.4 lbs	100 lbs
Rudder	256.4 lbs	150 lbs

D= diameter of the control wheel in inches (=10.63 in)

SARAS PFCS has been designed for the following pilot forces as per FAR part 23 Para 23.397
However, these values are likely to be refined during the technical discussion stage.

Table 4.2.2.3. Aileron Control and surface deflection

Control wheel rotation	Aileron Movement in deg	
	Left Aileron	Right Aileron
78°±1° Anticlockwise	25°±1° Up	15°±1° Down
78°±1° Clockwise	15°±1° Down	25°±1° Up

Table 4.2.2.4. Elevator Control and surface deflection

Position	Control column (deg)	Elevator (deg)
Aft (wrt neutral#)	15°±0.5°	30°±1° Up
Fwd (wrt neutral#)	12.5°±0.5°	15°±1° Down

Neutral is 10° forward to floor board normal

Table 4.2.2.5. Rudder Control and surface deflection

Position	Pedal movement	Rudder (deg)
Left Pedal - Fwd	135 ± 5 mm (no load) 170 ± 5 mm (under load)	20°/15°±1° Left
Right Pedal - Fwd	135 ± 5 mm (no load) 170 ± 5 mm (under load)	20°/15°±1° Right

Table 4.2.2.6. Gearing between servo motor & control surface

Control	**Gearing (Movement) between servo motor & control surface**	
Aileron	Up : 5.25:1.0	Down: 7.0:1.0
Elevator	3.0:1.0	
Rudder	2.5:1.0	

Table 4.2.2.7. Gearing (Movement) between control wheel/pedal & surface

Control	Gearing (Movement) between control wheel/pedal & surface	
Aileron	Up : 1: 0.2587	Down: 1: 0.214
Elevator	1: 1.9069	
Rudder	1: 1.8326	

Table 4.2.2.8. Gearing (Movement) between control wheel/pedal & servo motor

Control	Gearing (Movement) between control wheel/pedal & servo motor	
Aileron	Up : 1: 1.499	Down: 1: 1.498
Elevator	1: 5.8206	
Rudder	1: 4.5815	

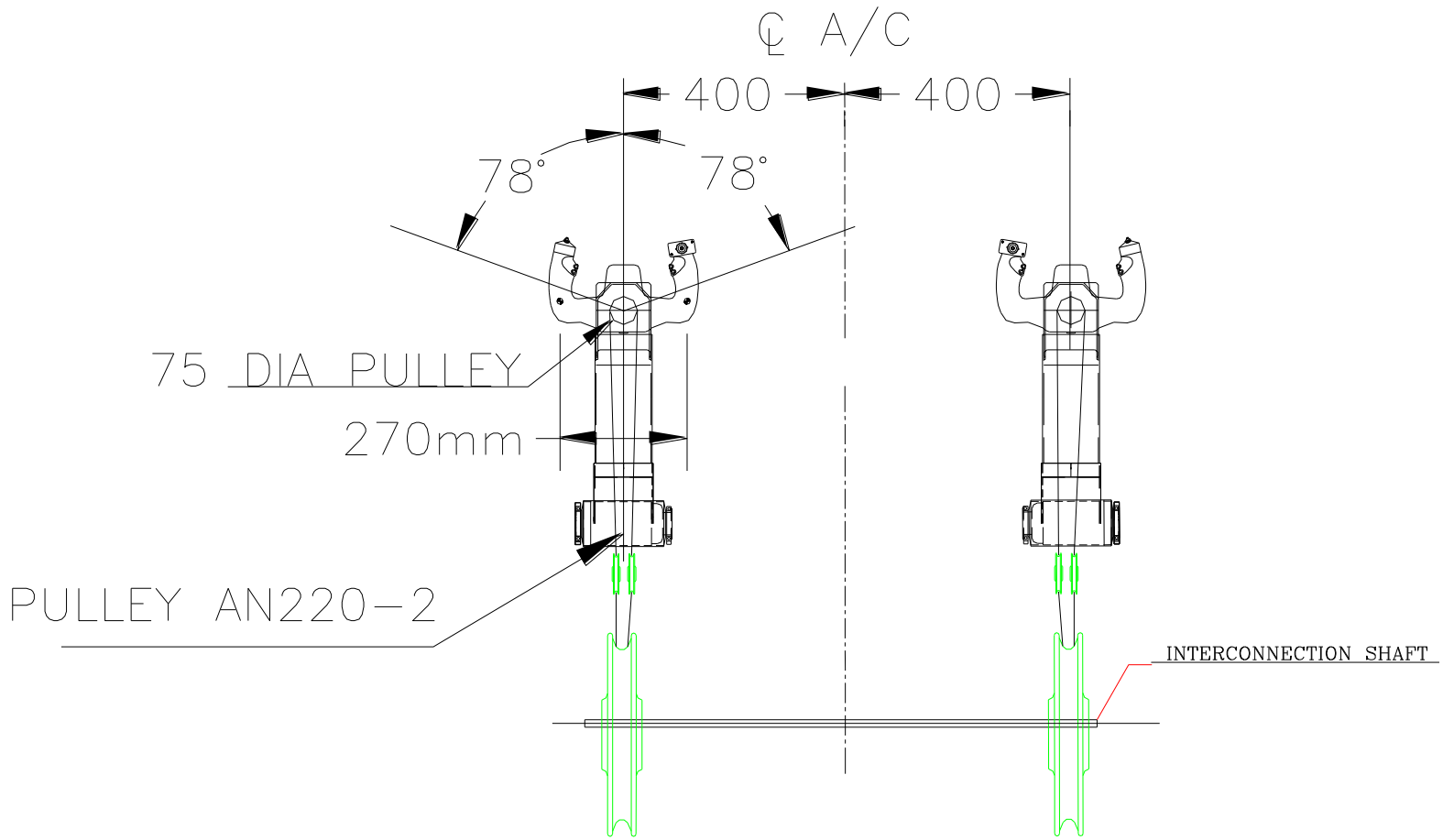
Table 4.2.2.9. Servo motor Torque (inch Lbs) = K* Wheel force(Lbs)

Control	K	
Aileron	Up : 7.09	Down: 7.09
Elevator	3.9909	
Rudder	3.01	

Table 4.2.2.10. Wheel force (kgf) = G. Hinge Moment(Kgm)

Control	G	
Aileron	Up : 1.9	Down: 1.42
Elevator	3.4 /m (for -30 deg. elevator); 2.03 /m (for +15 deg. elevator)	
Rudder	**For Pusher:** 2.58 /m (for 135 mm pedal deflection)- under no load; 2.05 /m (for 170 mm pedal deflection)- under load **For tractor:** 3.27 /m (for 160 mm pedal deflection); 4.36 /m (for 120 mm pedal deflection) – under no load; 2.73 /m (for 160 mm pedal deflection); 3.64 /m (for 120 mm pedal deflection) – under load	

All the primary control surfaces movements are measured using potentiometers.



All dimensions are in mm

Figure 4.2.2.1 Aileron Control Circuit

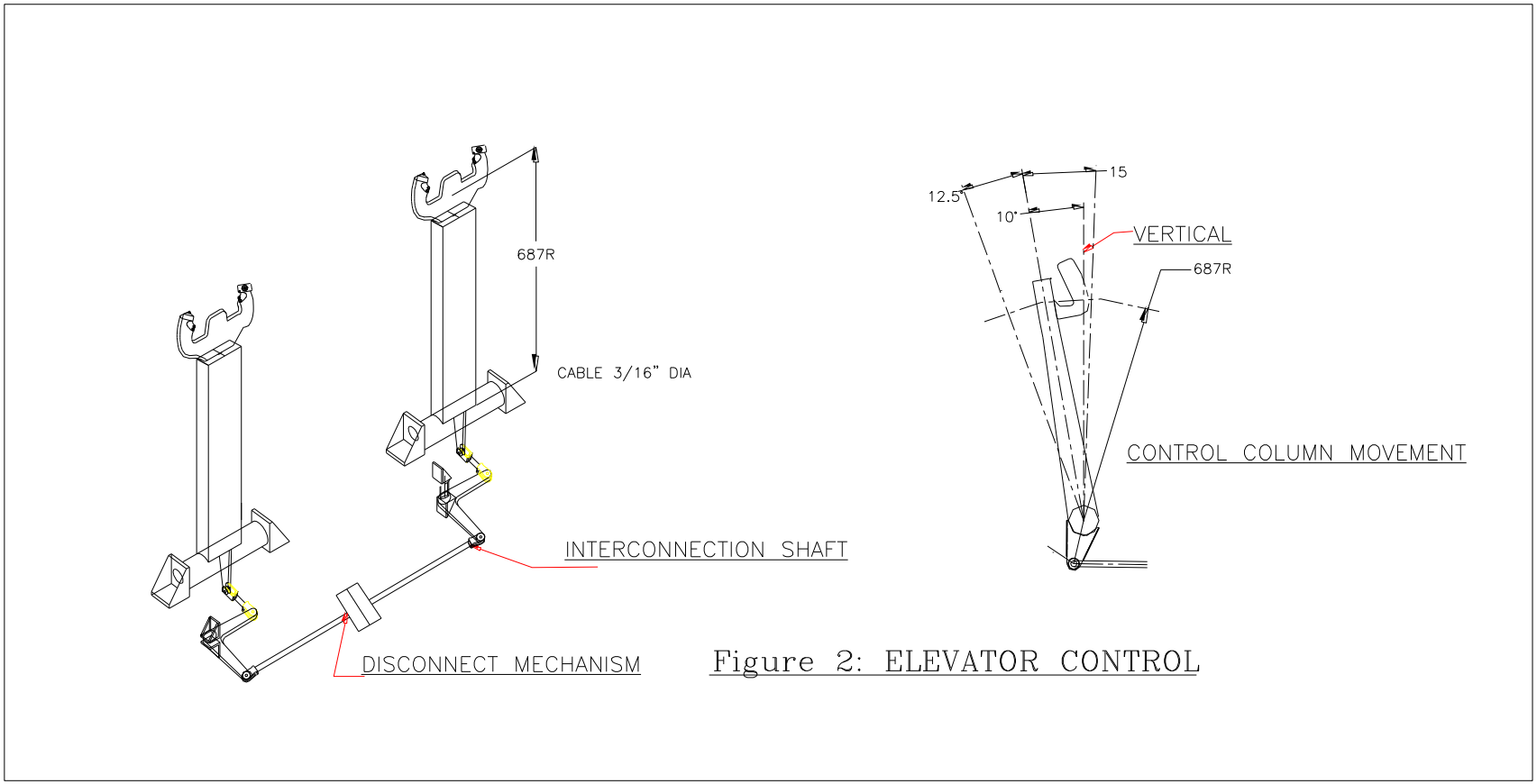
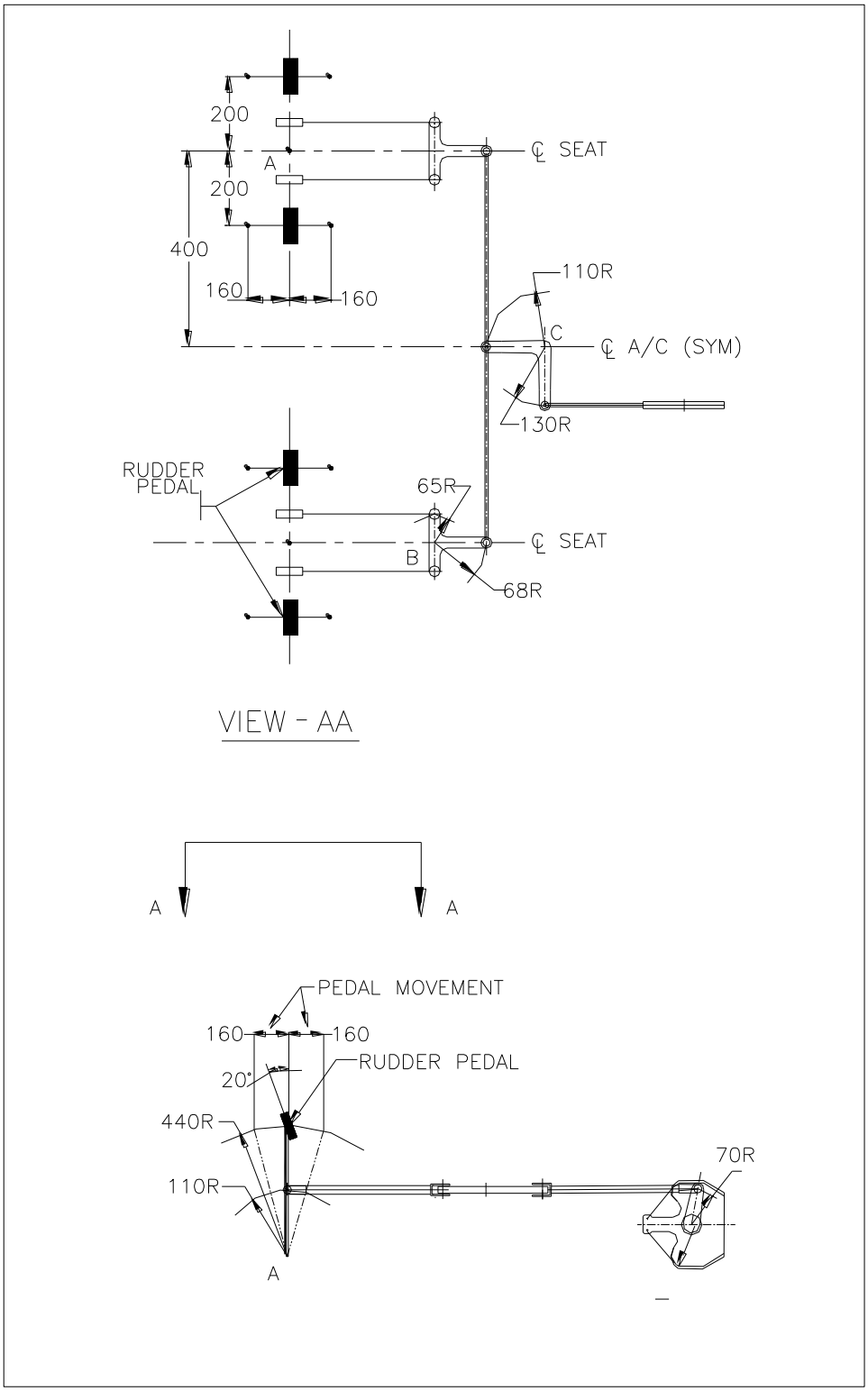


Figure 2: ELEVATOR CONTROL

Radius Of control column =687 mm

Figure 4.2.2.2 Elevator Control Circuit



All dimensions are in mm

Figure 4.2.2.3 Rudder Control Circuit

4.2.3 Design and Fabrication of Cradle and Linkages

4.2.3.1 Introduction

NAL is building a fixed base Fixed Base Training Simulator (FBTS) for its SARAS Mk2 aircraft to support Avionics and FCS testing. In addition to this, this facility will be used to familiarize the pilots with the aircraft systems and its flying qualities.

The PFCS of SARAS consists of reversible push-pull rods and cables connecting the control surface in each axis with the pilot controls in the cockpit. There are three primary axes pitch, roll and yaw, which need to be simulated in the FTD. The mechanical linkage from the pilot column to the cradle is shown in Figures 4.2.2.1, 4.2.2.2 and 4.2.2.3 for the aileron, elevator and rudder channels respectively. The gearing from pilot controls to the aircraft control surface and the autopilot motor location is presented in Tables 4.2.2.7 and Table 4.2.2.8.

4.2.3.2 Mathematical Modeling and Simulation

The mechanical PFCS of SARAS can be represented by idealized elements as shown in Figure 4.2.3.1. There is a mechanical gearing between the Forward and the Aft systems. A typical force Vs displacement plot of the PFCS is shown in Figure 4.2.3.2. The various parameters like friction, Aft and forward stops and the aerodynamic force gradient can be readily observed in this figure. These parameters inherent in the aircraft PFCS mathematical model (Fig. 4.2.3.1) are obtained by a measurement of the force Vs displacement (Fig. 4.2.3.2) at the pilot control column for various flight conditions in the aircraft. Similarly, dynamic response can also be measured.

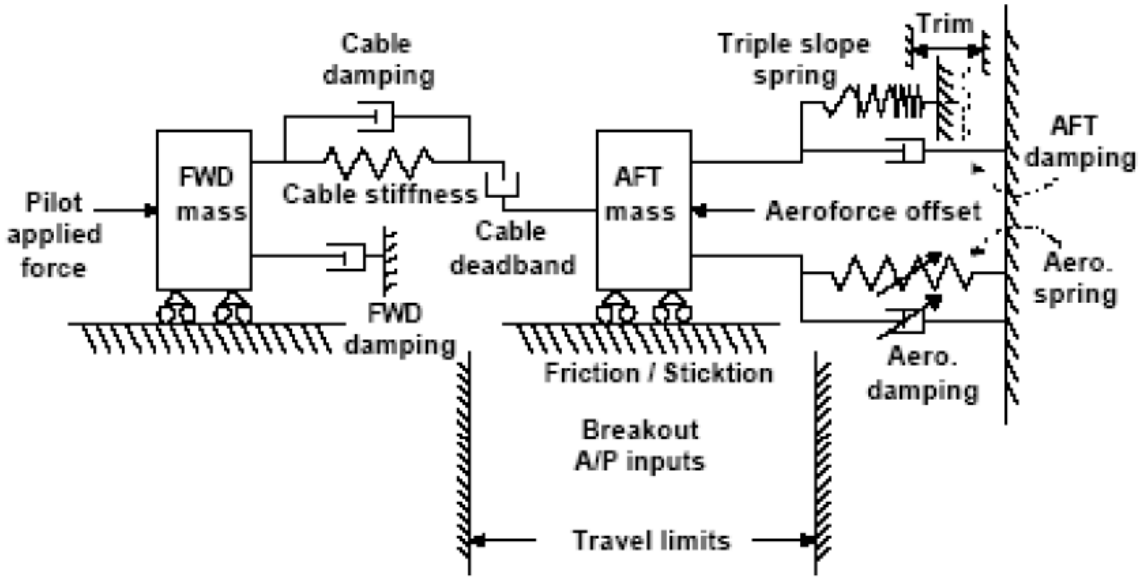


Figure 4.2.3.1. Equivalent Spring / Mass / Damper System of SARAS Mk2 mechanical PFCS

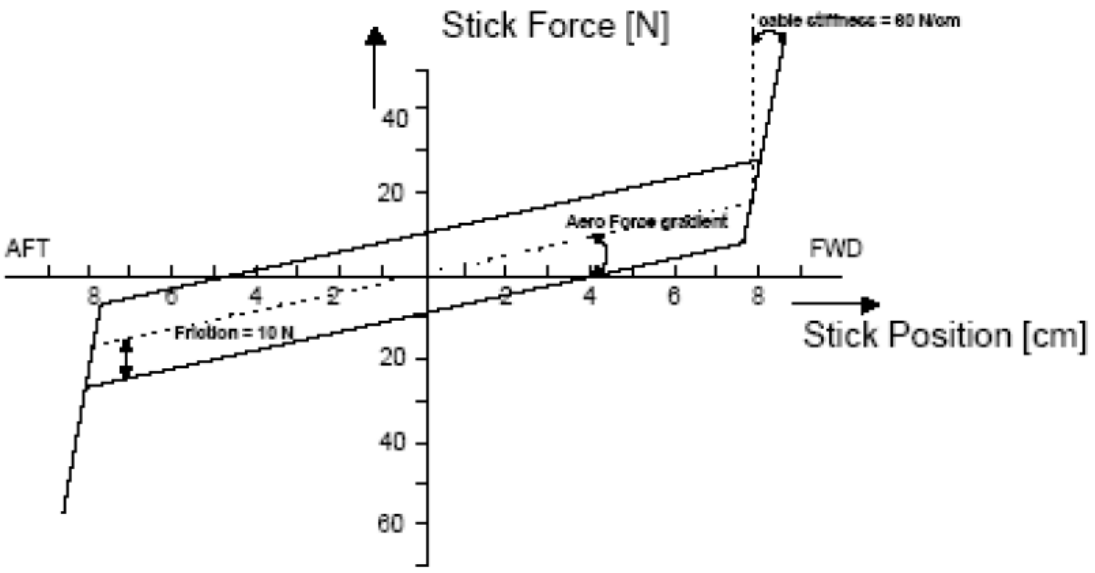


Figure 4.2.3.2. Airborne Control Feel of Manual Flight Control

In the simulator the static and dynamic response of the aircraft system represented by Figure 4.2.3.1 is reproduced. With the data as measured on the aircraft PFCS, the feel of the aircraft controls can be provided in the simulator by special purpose torque motors driven in closed loop.

4.2.3.3 Design of Control Loading Linkages and Cradle

The control loading motors in the simulator are mechanically linked to the pilot control column through linkages. These linkages are not identical to those in the aircraft. ideally, one would like to minimize the linkages in the simulator for the following reasons:

- The sum of the linkage friction in the simulator and that modeled in the mathematical model must equal that of the aircraft. Hence, it is desirable to have as low a friction as possible in the simulator linkage (Table 4.2.3.1).

- The freeplay of the simulator linkage are added to the simulation, and hence should be lower than the values to be simulated. This should be relatively simple to achieve, since the simulator linkage path is much shorter than the aircraft linkage part (Table 4.2.3.1).

- The stiffness of the simulator linkage should be more than two times the stiffness of the linkage in the aircraft (Table 4.2.3.1). Linkage stiffness is defined as the relationship between forces exerted at the flight control and the displacement of the flight control, if the other end of the linkage is completely fixed. The other end of the aircraft linkage is attached to the control surface; the other end of the simulator linkage is attached to the control loading actuator.

- The inertia of the linkages needs to be kept as low as possible so that the dynamic response of the inner loop in the control system can be tuned adequately.

- The linkage should have a mechanical gearing that makes optimal use of the travel of the actuator. IMPORTANT: do not use the entire stroke of the actuator to prevent cable damage when the actuator hits its internal hard stop. Preferably the design should be such that the actuator stroke required should be 2/3rd of entire stroke.

- The linkage should include cockpit stops at the identical location of the aircraft cockpit stops.

- The linkage should be equipped with safety stops. Strength of the linkage should be such that the safety stops and the linkage between the safety stops and the actuator can withstand the full force of the actuator. The linkage stops should be adjusted just outside of the (simulated) cockpit stops.

- An adjustable rod end may be installed for alignment of the actuator mid position.

- The linkages must be designed to maximize the linearity of the gearing over the entire range of travel of the pilot controls by minimizing the parallax.

Table 4.2.3.1. **Maximum Friction, Maximum Free play and Minimum Stiffness Targets for the linkages**

Axis	**Friction**	**Free play**	**Stiffness**
Pitch	<0.5kg at Pilot Stick with motor free	<0.05deg at Pilot Stick with motor end fixed	*150N/cm* at Pilot stick
Roll	<0.5kg at Pilot Wheel with motor	<0.5deg at Pilot Wheel with motor end fixed	> *180N/cm* at Control Wheel
Yaw	< 1 kg at Pilot Pedals with motor free	<0.05deg at Pilot Pedals with motor end fixed	> *180N/cm* at Pedal

The three control linkages of the simulator shall be mounted in a truss structure called the cradle. The cradle top view and side view are shown in Figures 4.2.3.3 and 4.2.3.4. It is mandatory that the torque tube of the pilot control column be placed in the same relative position with respect to the eye point as shown in Figure 4.2.3.4. **The details presented in Figures 4.2.3.3 & 4.2.3.4 are likely to be modified during the technical discussion stage.** Similarly, the rudder pedals must also be placed in the correct location with respect to the eye point. The pilot seating rails are to be mounted on the cradle at precisely defined locations (drawings and expected loads will be provided by NAL). The eye point itself has a fixed position with respect to the cockpit and the projection screen. It is desirable that the pilot control column, rudder pedals, CLS motors and the control linkages should be mounted directly on the cradle to achieve high stiffness. **NAL shall provide the pilot controls and the torque tube.**

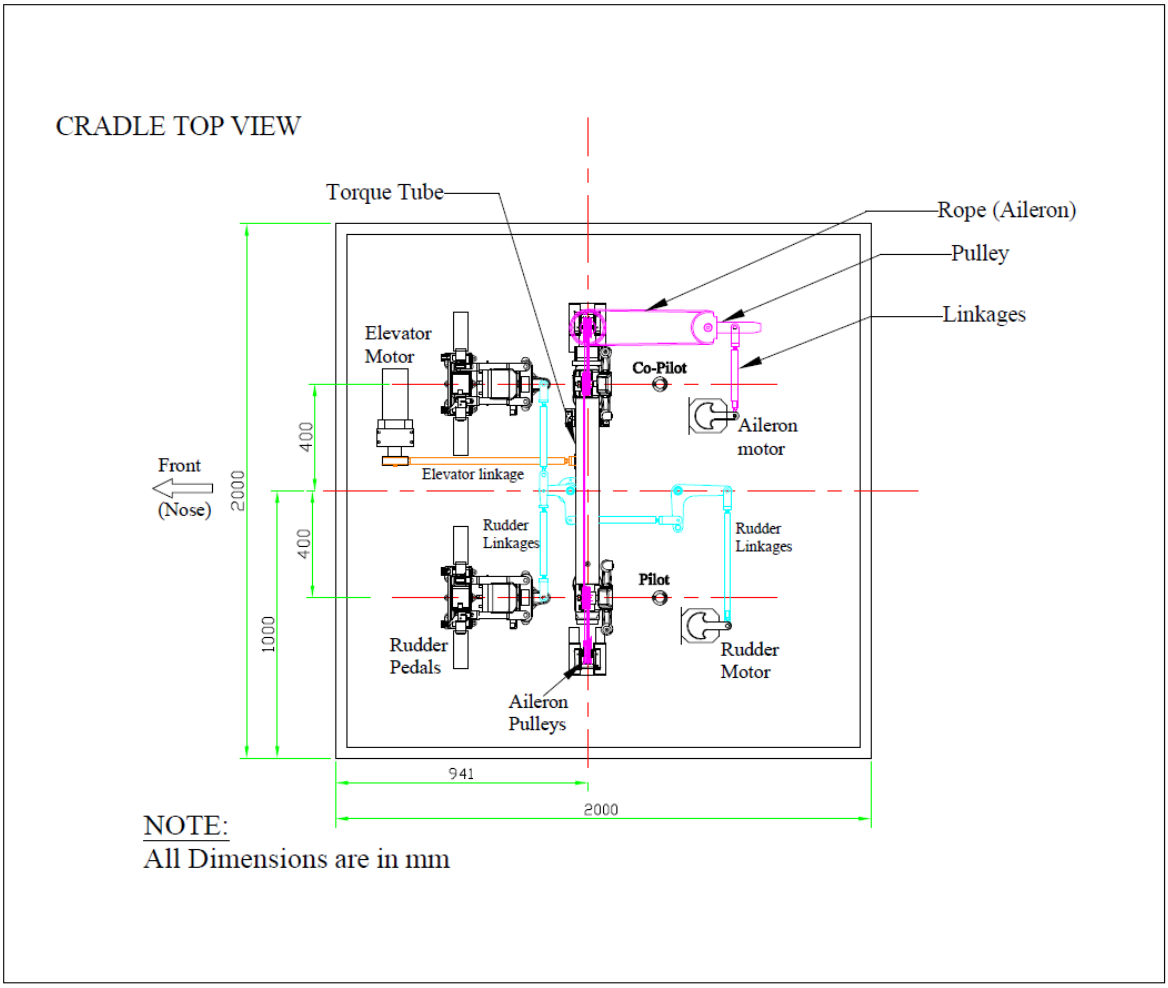


Figure 4.2.3.3. Top view of cradle

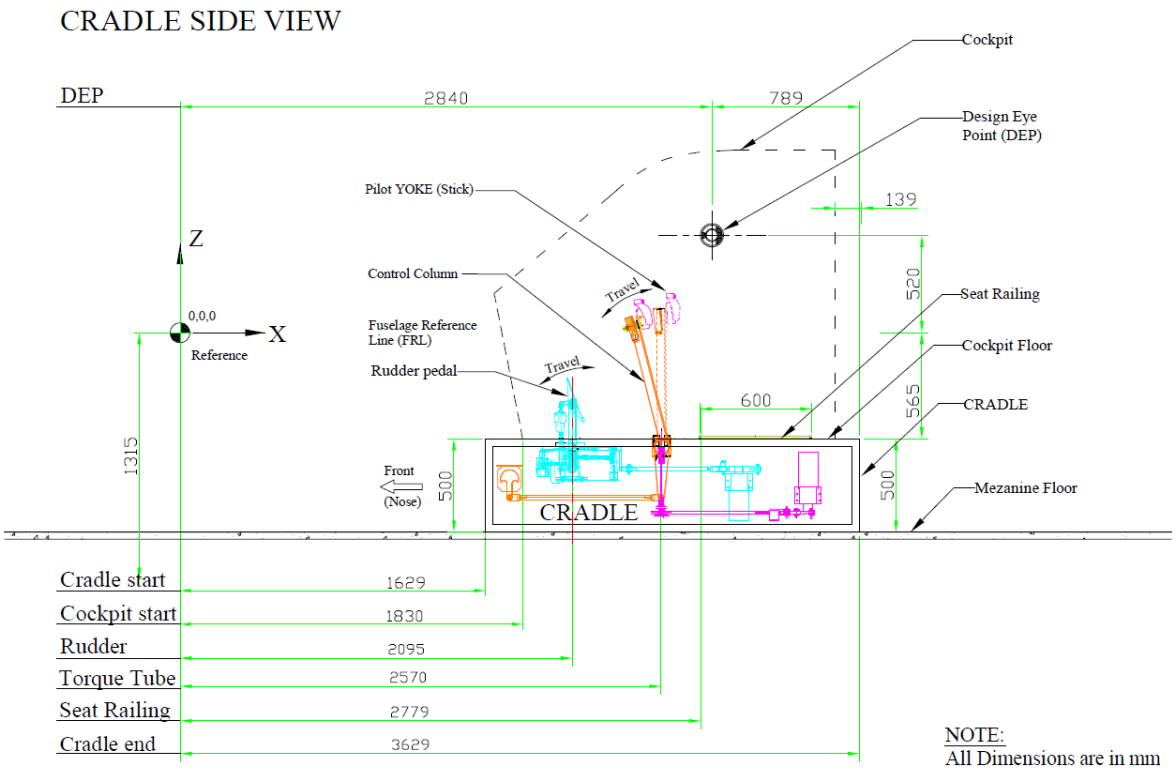


Figure 4.2.3.4. Side view of cradle

4.2.4 List of Deliverables:

Sr. No.	Item Description	Unit	Quantity
1	Control Loader Actuators, Interface electronics & cables	Nos	4
2	Control Loader Computer & Interface cables	Nos	1
3	Aircraft specific reference model of the reversible PFCS must be provided along with interface software, Daily Operational Readiness Test (DORT) and Diagnostics. Detailed Documentation shall be provided for the use of the reference model development system. Documents shall be provided to give clear guidelines to change the aircraft specific reference model displacement/force characteristics (software) as per user requirements.	Nos	1
4	compiler and tools required to compile and link the aircraft specific reference model with the rest of the control loader software	Set	1
5	Tuning software must be provided along with necessary documentation	Set	1
6	Detailed instruction manuals for the proper Installation of the system, daily operation / maintenance / fault diagnosis of the system	Set	1
7	Design report of the Cradle and Linkages along with report on static and dynamic analysis results for strength and stiffness against loads	Set	1
8	Fabrication and Installation drawings for the cradle and linkages.	Set	1

9	3-D model of the entire structure in IOES/ STEP format for review	Set	1
10	Fabricated Cradle and Linkages as per specification	Set	1

4.3 Scope of Supply and incidental works:

Scope of Supply includes the following:

(i) Supply of the equipment / system along with the accessories as per clause No.4.2

a) Detailed design of the linkages from pilot controls in three axes to the Control Loading Motors as per the Force (as per Table 4.2.2.2) and displacement meeting appropriate requirements in each axis (as per Tables 4.2.2.3, 4.2.2.4 and 4.2.2.5 respectively)

b) Detailed design document of the cradle to house:

(i) The mechanical linkages (Item 'a' above)

- Choice of gearing ratio between pilot controls and motors
- Justification of design choices leading to low friction and free play in the mechanical linkages.
- Static and dynamic analysis of the cradle and linkages for strength and stiffness against loads arising from components in Item 'a'.
- Fabrication and Installation drawings for the cradle and linkages.

(ii) Control Loading Motors (4 Nos).

c) The above document has to be supplied to NAL for verification before manufacturing/assembly

d) Hardware in the form of actuator assemblies, controller, DC servo motors, position / velocity resolvers, pilot force sensor, power and connecting cables for all the four actuators.

e) Control Loading Computer with Real Time Operating system that communicate with the host computer in real time at a minimum rate of 40Hz in order to update the hinge moment loads. Vendor shall demonstrate the communication with flight dynamic model.

f) 3-D model of the entire structure in IOES I STEP format for review.

g) Fabrication and Commissioning of the control loading structure as per Item b

h) Aircraft specific reference model of the reversible PFCS must be provided along with interface software, Daily Operational Readiness Test (DORT) and Diagnostics. Detailed Documentation shall be provided for the use of the reference 'model development system'. This model should have the capability to simulate autopilot actuators, stick shakers, surface stops, stick-to-surface cables or push-pull rods, spring breakouts, etc.

i) The vendor will also provide the compiler and tools required to compile and link the aircraft specific reference model with the rest of the control loader software.

j) Documents shall be provided to give clear guidelines to change the aircraft specific reference model displacement/force characteristics (software) as per user requirements. Any tuning required for the inner loop of the control loader needs to carried out at the time of installation at the site. However, tuning software must be provided along with necessary documentation. NAL should be able to modify the aircraft parameters and tuning parameters when required

k) The equipment shall be supplied with detailed instruction manuals for the proper Installation of the system, daily operation / maintenance / fault diagnosis of the system

l) The vendor shall install the actuator, controller in the cradle and install the linkage to the NAL supplied control column & rudder pedal.

ii) Pre-Dispatch Inspection as per Clause No.4.4.3

iii) Installation, Commissioning and Acceptance as per clause No.4.4.4

iv) Training as per clause no.4.5

v) On site comprehensive Warranty as per clause No.4.6.

vi) Annual Maintenance Contract as per clause No.4.7

vii) Delivery Schedule as per clause No.4.8.

Notes:

1. A presentation may be required during technical evaluation. Date, time and venue will be intimated at a later date.
2. All the equipment shall operate from 230 V, 50 Hz, single phase UPS or 3 Phase raw power and the total power requirements shall be specified.
3. If the system operates on 3 phase raw power, adequate backup for at-least 1 hour should be provided to operate the system under power failure.
4. The quotation shall include detailed specifications of all the elements constituting the control Loader system (hardware and software).
5. Specifications of the size of the 19" Rack system to house the equipment shall be provided.

4.4 Inspection & Tests

4.4.1 General

1. The Supplier shall at its own expense and at no cost to the Purchaser carry out all such tests and/or inspections of the Goods and Related Services as are specified here.

2. The inspections and tests may be conducted on the premises of the Supplier or its subcontractor(s), at the point of delivery and/or at the Goods final destination.

3. Whenever the Supplier is ready to carry out any such test and inspection, it shall give a reasonable advance notice, including the place and time, to the Purchaser. The Supplier shall obtain from any relevant third party or manufacturer any necessary permission or consent to enable the Purchaser or its designated representative to attend the test and/or inspection.

4. Should any inspected or tested Goods fail to conform to the specifications, the Purchaser may reject the goods and the Supplier shall either replace the rejected Goods or make alterations necessary to meet specification requirements free of cost to the Purchaser.

5. The Purchaser's right to inspect, test and, where necessary, reject the Goods after the Goods' arrival at final destination shall in no way be limited or waived by reason of the Goods having previously been inspected, tested and passed by the Purchaser or its representative prior to the Goods shipment.

6. The Supplier shall provide the Purchaser with a report of the results of any such test and/or inspection.

7. With a view to ensure that claims on insurance companies, if any, are lodged in time, the bidders and /or the Indian agent, if any, shall be responsible for follow up with their principals for ascertaining the dispatch details and informing the same to the Purchaser and he shall also liaise with the Purchaser to ascertain the arrival of the consignment after customs clearance so that immediately thereafter in his presence the consignment could be opened and the insurance claim be lodged, if required, without any loss of time. Any delay on the part of the bidder/ Indian Agent would be viewed seriously and he shall be directly responsible for any loss sustained by the purchaser on the event of the delay.

8. Before the goods and equipment are taken over by the Purchaser, the Supplier shall supply operation and maintenance Manuals together with Drawings of the goods and equipment built. These shall be in such details as will enable the Purchase to operate, maintain, adjust and repair all parts of the works as stated in the specifications.

9. The Manuals and Drawings shall be in the ruling language (English) and in such form and numbers as stated in the Contract.

10. Unless and otherwise agreed, the goods and equipment shall not be considered to be completed for the purposes of taking over until such Manuals and Drawing have been supplied to the Purchaser.

11. On successful completion of acceptability test, receipt of deliverables, etc. and after the Purchaser is satisfied with the working of the equipment, the acceptance certificate signed by the Supplier and the representative of the Purchaser will be issued. The date on which such certificate is signed shall be deemed to be the date of successful commissioning of the equipment.

4.4.2 Manufacturer's Inspection Certificate`

After the goods are manufactured and assembled, inspection and testing of the goods shall be carried out at the supplier's plant by the supplier, prior to shipment to check whether the goods are in conformity with the technical specifications. Manufacturer's test certificate with data sheet shall be issued to this effect and submitted along with the delivery documents. The purchaser reserves the options to be present at the supplier's premises during such inspection and testing.

4.4.3 Pre Dispatch Inspection

1)	Location	At manufacturers premises.
2)	Number of persons	02
3)	Period of Pre Dispatch Inspection	5 days
4)	Nature of Pre Dispatch Inspection	Inspection of the cradle and linkages against dimensions
		Software Configuration Tests
		Hardware Configuration Tests
		Hardware Functionality Tests
		Safety System Tests including: a) Force Trip Level b) Velocity Trip Level c) Power Trip Level d) Fail safety demonstration
		Hardware Performance Tests including: a) Maximum continuous force test b) Maximum velocity test c) Maximum acceleration test.

4.4.4 Installation, Commissioning and Acceptance Test

The acceptance test will be conducted by the Purchaser, their consultant or other such person nominated by the Purchaser at its option after the equipment is installed at Purchaser's site in the presence of supplier's representatives. The acceptance will involve trouble free operation. There shall not be any additional charges for carrying out acceptance test. No malfunction, partial or complete failure of any part of the equipment is expected to occur. The Supplier shall maintain necessary log in respect of the result of the test to establish to the entire satisfaction of the Purchaser, the successful completion of the test specified.

On the event of the ordered item failing to pass the acceptance test, a period not exceeding two weeks will be given to rectify the defects and clear the acceptance test, failing which, the Purchaser reserve the right to get the equipment replaced by the Supplier at no extra cost to the Purchaser.

Successful conduct and conclusion of the acceptance test for the installed goods and equipment shall also be the responsibility and at the cost of the Supplier.

The acceptance tests at the final destination include the following:

a)	Acceptance of the final design document against NAL requirement.
b)	Hardware Configuration Tests
c)	Hardware Functionality Tests

d)	Safety System Tests 1. Force Trip Level 2. Velocity Trip Level 3. Power Trip Level 4. Fail safety demonstration
e)	Hardware Performance Tests 1. Maximum continuous force test 2. Maximum velocity test 3. Maximum acceleration test.
f)	Inspection of the cradle and linkages against dimensions
g)	Inspection of the cradle and linkages against the friction, freeplay and stiffness
h)	Demonstration of functioning after integration and tuning of aircraft model and inner loop tuning of the control loader as per NAL requirements.

4.5 Training

1)	Location	CSIR-National Aerospace Laboratories, Bangalore
2)	Number of persons	03
3)	Period of Training	5 Working Days
4)	Nature of Training	Training on operation, maintenance and tuning

4.6 Incidental Services

(i) **On site Comprehensive Warranty**:

- **1 Year** from Installation & Commissioning and date of acceptance
- In case the Equipment / System remains non-operational for more than **30 days** then warranty period will be extended for the equivalent period for which Equipment / System remained non-operational. Warranty extension in such case shall be done without prejudice to any other Term & condition of the contract

4.7 Annual Maintenance Contract:

- AMC for a period of 5 years after completion of warranty period for Control Loading Motor and Controller. The Bidder is responsible to maintain the system under calibration during the AMC period. However, AMC cost shall not be a part of price comparison.

4.8 Delivery Schedule (including supply, installation, commissioning, training & acceptance)

<table>
<tr><th colspan="2">Delivery of the Item</th><th colspan="2">Installation & Commissioning</th><th>Training At CSIR_NAL, if any</th><th>Acceptance of the item</th></tr>
<tr><th>Days/ Weeks/Months</th><th>Location</th><th>Days/ Weeks/Months from the date of receipt of equipment</th><th>Location</th><th>Days/ Weeks/Months from the date of Installation & Commissioning</th><th>Days/ Weeks/Months from the date of Installation, Commissioning & Training</th></tr>
<tr><td>(1) Design document should be released and accepted within 2 months from the date of PO.</td><td rowspan="2">FMCD, CSIR-NAL, KODIHALLI, BENGALURU – 560 017</td><td>-</td><td rowspan="2">FMCD, CSIR-NAL, KODIHALLI, BENGALURU – 560 017</td><td colspan="2">----</td></tr>
<tr><td>(2) Supply of items within 4 months from the date of acceptance of design document</td><td>Within 4 weeks</td><td>Within 1 week after commissioning</td><td>Within 15 working days after commissioning</td></tr>
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