Draft Proposal for an FDR of the delay line prototype

Version 4.0 - Martin Fisher 15th February 2007

1 Introduction

The project stages for the MROI delay lines differ from the most common practice because of the unique concept and its associated risk. It was necessary to carry out proof of concept or risk reduction experiments and review these before proceeding to the detailed design and testing of a prototype. For comparison, the conventional project flow and Delay Line project flow are shown in Figure 1. Here the risk reduction experiments replace the preliminary design phase and the Risk Reduction Review replaced the PDR stage. Note that in this document a phase refers to a specific period of activity while a stage is a particular event, such as a review. The prototype design, development and testing phase replace the detailed design phase but, nevertheless, still culminate in a Final Design Review. This proposal outlines the structure of this review and proposes a set of review documentation that would often be defined in a Statement of Work (SOW).

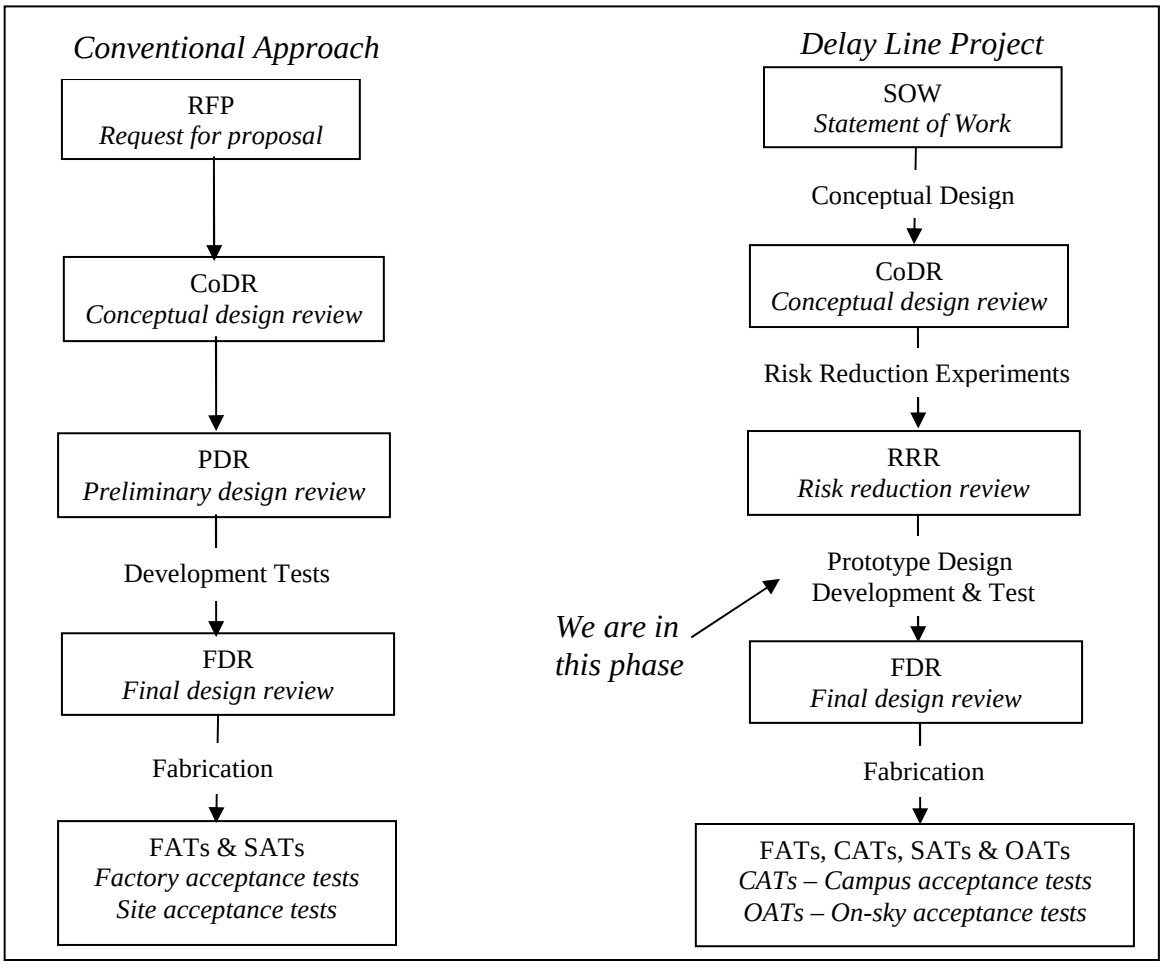

Figure 1 Conventional and Delay Line project phases and stages. Following the prototype design, development and test phase, the Final Design Review (FDR) is the stage which approves the prototype design, including any amendments, and permits fabrication of the first production trolley.

2 Project Phases and stages

Assuming a successful FDR, the fabrication phase produces one production trolley which undergoes Factory Acceptance Tests (FATs) at Cambridge followed by a similar set of tests, referred to as Campus Acceptance Tests (CATs), at NMT. At this point the contract may be considered fulfilled in terms of the deliverables but in terms of follow-up support there may follow a set of Site Acceptance Tests (SATs) in which the full 100m/200m delay line is tested with the production trolley and later yet, a set of On-sky Acceptance Tests (OATs) which are tests with starlight.

2.1 Prototype design, development and test phase

The project is now in the stage of detailed design, manufacturing and testing of a prototype trolley which will be tested in a twenty metre length of delay line pipe. The tests are intended to exercise all the operational and safety functions of the trolley and delay line except for the introduction of a science beam. Development and testing of the prototype are undertaken in an incremental manner until the complete prototype can be tested as a system in the COAST bunker which houses the 20m long delay line test rig. The final prototype testing phase should be followed by a period of assessment of the results. Also any required or desired design changes which have not been incorporated into the prototype should be assessed. The output from the tests and assessment would be an FDR report containing the current design of the prototype, the test results obtained with this design and details of any proposed design changes. This report should be made available to reviewers two weeks before the final design review is scheduled.

2.2 Final Design Review stage

FDR reviewers should be familiar with the project but if not there are a number of project documents which NMT could make available to them, in addition to the FDR report, which describe the concept. More information on this and on the documentation supporting the items under scope of the review is given in section 5.2

2.2.1 Scope of the Review

The proposed scope of the review (which defines the FDR inputs for assessment) is given below:

1. The prototype trolley
    - Subsystem requirements
    - Performance of trolley
    - Design of trolley
    - Interface requirements
    - Proposed design changes to be incorporated into the production trolley, if any

2. The delay line structure
    - Subsystem requirements
    - Performance of prototype delay line test rig
    - Design of prototype delay line test rig
    - Proposed design for pipeline of 200m delay line
    - Interface requirements

3. Interface to the DL building BCA and facilities
    - Interface requirements
    - Proposed designs and descriptions

4. Documentation Plan

5. Acceptance Test Plans

2.2.2 Outputs of the Review

The output of the review is usually a chairman's report. In outline, the review team should:

1. Review the subsystem requirements which are derived from the system requirements.
2. Consider the performance results with regard to the subsystem requirements.
3. Review the current design of the prototype system.
4. Assess any proposed design changes to be made for the production version.
5. Assess the Documentation and Acceptance Test Plans.
6. Report and make recommendations on how to proceed.

3 Further Phases

To put the requirements of the FDR into perspective the phases following it should also be considered and include specific deliverables at each stage. Proposals for these are outlined below.

3.1 Fabrication Phase

- Fabricate production model trolley, incorporating any design changes approved under the change request procedure.
- Test production trolley on the 20m test rig.
- Provide an 'acceptance data package' which includes a performance report for this trolley plus the set of data files of test results.
- Complete documentation (build-to designs and all user documentation).
- Agree and arrange FATs

3.2 Factory Acceptance Tests

- Carry out factory acceptance tests at Cambridge (these tests could be a subset of the production model trolley tests but in any case are based on the acceptance tests proposed at FDR and subsequently agreed with NMT).
- Review test results and current documentation set.
- Agree proposals for CATs.

3.3 Campus Acceptance Tests

- Cambridge will provide sufficient detail to allow NMT to produce a suitable local test facility in order for Cambridge to carry out the CATs
- NMT will build and test, as far as is practicable, the campus test rig.
- Cambridge will unpack, re-assemble and align production trolley.
- Cambridge and NMT will jointly complete alignment and test of the campus test rig.
- Cambridge will carry out the agreed set of CATs with NMT representatives as witnesses.

3.4 Site Acceptance Tests

- Install and test of delay line pipe (vacuum tests, alignment etc).
- Re-assemble and align production trolley if necessary.
- Carry out agreed set of SATs
- After suitable period release as-built drawing and documentation.

3.5 On-sky Acceptance Tests

Not defined at this time. Submit preliminary definition at FDR and agree full set of tests at SAT time.

4 Timing of FDR

4.1 Date of the FDR

The FDR should take place after the assessment and report production period following the full prototype testing on the 20m test rig. The tests are expected to be complete by the middle of June 2007 and the assessment and report by end of first week in July 2007. I suggest that the FDR should take place in the last week of July 2007.

4.2 FDR Location and Schedule

The FDR should take place in Cambridge and last for no longer than two days. Panel members from NMT would be likely to attend in person while ‘external’ reviewers may also attend or may phone in according to circumstances. All panel members would take part in a concentrated session where most of the key issues could be discussed. NMT members would stay on for a demonstration of the prototype trolley and for further discussions. A preliminary agenda is given in Appendix I.

5 Final Design Review Content

While the content of the review is driven largely by the extent of the review as proposed above there is also a connection to the deliverables defined in the Statement of Work for the contract and the associated schedule for delivery. The deliverables and the relationship to the schedule are discussed below and then followed by a proposal outlining the content of the review.

5.1 Deliverables defined in the SOW

The Statement of Work defines what is to be delivered under the contract but does not detail when certain items need to be either delivered or presented in draft form by particular milestones during the work. The relationship of the deliverables to the schedule is provided in the document 'Deliverables and Milestones' dated 21st December 2006. The list of deliverables given in the SOW is, in short:

D1 System requirements documents
- Doc 1: Top level functional requirements
- Doc 2: Mechanical interface document for pipe & supports
- Doc 3: Interface document for delay line "system"
- Doc 4: Requirements document for pipe (as vacuum vessel)

D2 Build to drawings of delay line carriages
D3 Build to drawings of delay line control electronics
D4 Build to drawings of delay line pipe joints and supports
D5 Build to drawings of delay line metrology system
D6 Build to drawings of test assemblies
D7 Parts and supplier lists
D8 Acceptance test procedures for all assemblies
D9 Assembly instructions for all assemblies
D10 Test procedures for all subsystems
D11 Prototype control software and documentation
D12 First production carriage and control electronics

The individual documents listed under D1 have differing delivery times since they are closely linked to Interface Control Documents (ICDs) which must be provided and agreed at the appropriate time. A brief description is given here:
- Doc1 is a top-level functional requirements document which does not exist yet as a single identifiable document. The information can be brought togther from two documents: *A System Design for the MRO Interferometer (Rev. 1.3 2002/10/24)* and *Results of the Risk Reduction Experiments - Revision1.0 6th December 2005* which sets out the derived requirements.
- Doc2 and Doc3 are specifically concerned with interfaces and will be ICDs.
- Doc4 is required for determining, in conjunction with manufacturers, the exact specification for production of the delay line pipe.

Deliverables D2 to D12 are clearly deliverable, formally, at the end of the contract but some intermediate information exchange is required for both interface control and for review of the project. In D4 for example, some information on the delay line pipe and supports is required to be finalised so that the interface to the building can be defined and the procurement of pipe can proceed.

Preliminary versions of documents containing outline contents but not necessarily low-level detail are often used for reviews or for communication of information throughout the project. They may be

parts descriptions, outline test procedures or areas where further explanation or supplementary information of interface control is required. Examples of these would be D5, D7 and D8.

5.2 Review Documentation

In this section we propose the set of documents that would be presented for the final design review. Apart from documentation which provides reviewers with an overview of the project, a set of clear and concise documents is needed for critical assessment of both the design and performance of the prototype delay line. A definitive list of these documents and their content should be agreed well before the review so that there is time to produce them. Such a list, based on the items under the extent of the review, is provided here and described in more detail below.

- System Requirements Flow-down Document (for information only)
- Delay Line System
- Delay Line Trolley
- Delay Line Structure
- Metrology and shear detector system
- Delay Line prototype software (for information only)
- Interface Requirements Documents
- Safety and Technical Risks
- Verification Plan
- Shipping Plan
- Schedule and Risks

The System Requirements Document outlines the design of the system and specifies the derived requirements. More detailed review documentation is grouped under the major subsystem headings and describes the specific design and interface requirements, the current design of the prototype (including any proposed modifications), the level of performance and the test results obtained with the prototype and preliminary documentation which provides at least a list of contents if not draft sections.

5.2.1 The System Requirements Flow-down Document

System description
Derived requirements

5.2.2 The Delay Line System

Design Requirements
Interface requirements
Design description and drawings of the prototype
Verification matrix and test results from the prototype
Preliminary Documentation

5.2.3 The Delay Line Trolley

Design Requirements
Interface requirements
Design description and drawings of the prototype
Verification matrix and test results from the prototype
Preliminary Documentation

5.2.4 The Delay Line Structure

Design Requirements
Interface requirements
Design description and drawings of the prototype
Test results from the prototype
Verification Plan (proposal) for pipes and supports
Preliminary Documentation

5.2.5 The Delay Line Prototype Software

Prototype Software Functional Description

5.2.6 The Metrology and Shear Detector System

Design Requirements
Interface requirements
Design description and drawings of the prototype
Verification matrix and test results from the prototype
Preliminary Documentation

5.2.7 Interface Requirements Documents

Interface Requirements Documents.

5.2.8 Safety and Technical Risk

Risks and Risk Management Plan
Hazards
Safety Requirements

5.2.9 The Verification plan

The Verification Plan we propose to follow describes the verification process, provides verification and performance matrices (which present information in a concise form), and assigns place-holders to acceptance tests and procedures where applicable. It also defines the contents of the Acceptance Data Package which underpins the acceptance process. The Verification plan is described in more detail in the following section.

5.2.10 Shipping Plan

The shipping plan describes the procedures for disassembling, packing, shipping, unpacking and reassembly of the production trolley.

5.2.11 Schedule and Risk

This is a presentation of the remaining project schedule, any deviations or design changes expected and an evaluation of schedule risks.

5.3 Verification Plan Content

The Verification Plan is an important document which is used to define and agree the process which leads to acceptance. The plan is a proposal which is presented for review and comment at the FDR and should be agreed a short time afterwards. It describes the methods to be used in verifying the design and performance for each subsystem. The basis of the Verification Plan is the Compliance Matrix. This lists each requirement and the method(s) by which it is judged compliant together with an associated location. When fully developed the plan also contains a reference to a specific acceptance test procedure where appropriate. Acceptance test procedures should be available one month before acceptance testing takes place. Unless specified in the SOW, the documentation required as part of the acceptance process is also defined in the verification plan and referred to as the Acceptance Data Package. This is briefly described in section 5.3.4.

5.3.1 Verification definitions

An example compliance matrix is provided below. Each requirement is verified by at least one verification activity. The verification activities are Design, Analysis, Inspection and Test and are listed in order of sequence through the project. Not all requirements would necessarily be subject to verification by test (e.g. earthquake analysis) but some requirements may be subject to all verification activities through the project lifetime. The following is an explanation of the headings which are used in the compliance matrix.

Compliance:
The item is awarded a compliance level when the last verification activity indicated in the matrix is completed.

Technical Verification:
Technical Verification is a specific and formal process of acceptance test which demonstrates compliance at a higher level than individual sub-system tests. For final acceptance (on site) it is not necessary to repeat all subsystem tests and so Technical Verification proposes those tests that would be performed as part of formal acceptance.

Verification by Design:
This is verification of the design by reference to sub-system and part specifications and to drawings which are provided as part of the Acceptance Data Package.

Verification by Analysis:
The performance of the specific item will be demonstrated by carrying out appropriate analyses, the results of which are provided as part of an Acceptance Data Package.

Verification by Inspection:

The compliance will be verified by certification or inspection by qualified personnel, optionally witnessed.

Verification by Test:
The performance of the specific item will be verified by specific tests, optionally witnessed.

5.3.2 Example Compliance Matrix (see Table Key)

Delay Line Trolley Section No.	Heading	Compliance	Technical Verification.	Design	Analysis	Inspect	Test	Location	Reference/notes
4.3.1	Shear Control Requirement	C			x				Flowed down to all Sub-system specifications
4.3.1.1	Tip-tilt range	C		x			x	F	Test ref 4.3 item 2
4.3.1.2	Tip-tilt Bandwidth	C			x		x	F	Test ref 4.3 item 3
4.3.2.1	Shear sensor range	C		x			x	F	Test ref 4.3 item 4
4.3.3	Shear correction level		x				x	F/S	Test ref 4.3 item 5

TABLE KEY:
Column 1: gives the document and section number where the requirements are found
Column 2: This column gives a summary description of the item requirement
Column 3: The entries in this column indicate the compliance of each item. There are four levels of compliance:

C	Compliant
TBC	To Be Confirmed - expected to comply, but requires confirmation
PC	Partially Compliant
NC	Non-Compliant

Column 4: Those tests identified as part of the formal Technical Verification process are identified in this column.

Column 5-8: The specific verification method proposed for each item is marked by an ‘x’ in the appropriate column.

Column 9: This column gives the expected location of the verification activity:

F: FATs - verification at sub-contractors facility
C: CATs - verification at Campus
S: SATs - verification at site
O: OATs - verification on-sky

Column 10: The specific document references used to prove (or allow independent scrutiny of) compliance are given in this column.

Table Key:

Symbol	*Meaning*
C	Item is Compliant with specification
TBC	Item is expected to Comply but requires confirmation
PC	Item is Partially compliant with specification
NC	Item is Non-compliant with specification
x	Verification method, or identifying a Technical Acceptance test
F	Item is verified at sub-contractors facility location
S	Item is verified at installation Site location

5.3.3 Performance Matrix

The performance matrix lists each specific requirement which has a quantitative component and the corresponding quantitative result obtained by design, analysis, component specification or certificate, or by test or some combination of these. An example (NOT real numbers) is given below.

Section No.	Heading	Requirement	Design	Analysis	Inspect	Test	Results/Comments
4.3.1	Shear Control Requirement						
4.3.1.1	Tip-tilt range	±4.2mrad			x	x	Specification ±5mrad
4.3.1.2	Tip-tilt Bandwidth	2 Hz		x		x	3 Hz (Dynamic Simulation)
4.3.2.1	Shear sensor range	±5mm at pipe	x			x	±7mm (Chip size & optics design)
4.3.3	Shear correction level	±0.5mm				x	±0.1mm achieved

5.3.4 Acceptance Data Package

The Acceptance Data Package is formally presented at the culmination of the acceptance process and comprises, where relevant:

- As built drawings and documentation
- User manuals
- Maintenance manuals
- Sub-system acceptance data packages
- Verification data package
- Software configuration
- Samples and certifications
- Manufacturer’s specification sheets and manuals

The Acceptance Data Package can be hierarchical in that sub-systems may have there own level of acceptance data packages with similar contents. In the case of the Delay Line Project it is unlikely that there will be more than one level.

The Verification Data Package will contain the results obtained throughout the verification process as defined in the Verification Plan.

5.4 Acceptance Tests

5.4.1 Hardware

Normally the set of acceptance tests should be proposed at FDR stage in the Verification Plan and agreed well in advance of the actual test period. For well-defined projects proposals for acceptance tests may be presented at PDR stage or even as part of the contract. The acceptance test plan presented at FDR should provide sufficient detail to allow NMT to produce a suitable local test facility in order for Cambridge to carry out the CATs.

Acceptance Test procedures should be written sufficiently in advance of the expected acceptance test phase and presented one month before the start. These procedures briefly describe the test, state the requirement or success criteria, the equipment needed to carry it out and any post-test analysis may be required to obtain the results.

In principle, FATs, CATs and SATs should be drawn from or share the same set of acceptance tests. For SATs the list may need to be extended if there are items specific to the 200m length of delay line. All of these acceptance tests can be defined by one list with exceptions (if there are any) for those things that could only be tested on a 200m delay line.
So far all the acceptance tests are based on performance obtained and measured through the metrology system plus measurements from on-board sensors. The On-sky Acceptance Tests assume that the delay line components are all functioning to specification and will require a different set of tests to be performed using starlight. This set of tests needs to be carefully thought through and presented at least in preliminary form at the FDR.

5.4.2 Software

Under the prevailing contract the software that is written by MRAO to control, demonstrate and test the production trolley may or may not be re-used by NMT. The software will control all the functions of the trolley and be robust and sufficiently comprehensive to demonstrate acceptance of the hardware, as defined in the verification plan. It will also be clear enough and sufficiently well documented that the functionality and performance could be reproduced by NMT. Acceptance of this, as a product, is not a clear process and therefore needs further discussion. The software being provided under the current contract may require a small amount of additional work if OATs are to be demonstrated. If an additional contract is issued which requires MRAO to write ‘production’ software then acceptance of the production software would be a separate process from delivery of the first contract.

Appendix I

Preliminary FDR Agenda

Day One - Morning (for both internal and external reviewers)

09:00 Welcome and introductions

09:15 Overview of top level requirements and flow-down into subsystem requirements – for information only

09:30 Presentation of design and performance expectations

10:30 Presentation of test procedures and results from the prototype trolley together with a comparison with performance requirements

12:00 Reviewer's closed session if required

Day One – Afternoon (for visiting review members)

12:30 Lunch

14:00 Demonstration of test rig at COAST

Day Two – Morning (for internal reviewers)

09:00 Discussion of schedule, cost, and risks

10:30 Discussion of interface issues and resources needed for these interfaces

11:30 Consideration of list of deliverables

12:30 Lunch

Day Two – Afternoon

14:00 Closed Session for internal reviewers

15:00 Informal feedback to Cambridge team followed by discussions.