DOT/FAA/AR-xx/xx

Office of Aviation Research
Washington, D.C. 20591

The Upgrade and Modernization Of the Walter H. Beech Memorial Wind Tunnel

August 2005

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-XX/XX		

4. Title and Subtitle	5. Report Date
THE UPGRADE AND MODERNIZATION OF THE WALTER H. BEECH MEMORIAL WIND TUNNEL	**August 2005**
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Laffen, John; Miller, L. Scott; Loper, Gerald; and Tomblin, John	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
National Institute for Aviation Research Wichita State University 1845 Fairmount Wichita, KS 67260-0093	
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591	Final Report
	14. Sponsoring Agency Code
15. Supplementary Notes	

16. Abstract

The Walter H. Beech Memorial Wind Tunnel is the landmark facility of the Aerodynamic Laboratories of the National Institute for Aviation research on the campus of Wichita State University in Wichita, Kansas. It was built during the winter of 1947-48 as a response to the need for aerodynamic research needed to support the booming aircraft companies in the Wichita area. Although properly maintained and improved over the years, the technology employed in the tunnel and its equipment were beginning to become dated and not useful to its clientele, which includes commercial, industrial, and academic interests.

At the request of industry, federal, state, and local officials and in conjunction with Wichita State University and the National Institute for Aviation Research representatives, a request was made for federally-appropriated funds through the Federal Aviation Administration and State of Kansas bond sales to fund a major upgrade and modernization of the Walter H. Beech Memorial Wind Tunnel. The facility was in dire need of a major upgrade and modernization if it was to continue its place in providing necessary aeronautical research to the aviation community in Wichita and beyond.

The funds were approved and the go ahead for the project was granted during September of 2001. Construction was complete in the spring of 2004 with shakedown work following. January 28, 2005 marked the official rededication of the facility.

The result of this $6M investment is the highest state-of-the-art wind tunnel facility of its class in North America in terms of equipment expenditures. The Walter H. Beech Memorial Wind Tunnel (Beech Wind tunnel) as it now stands has a brand new, custom built 2,500 horsepower fan that enables empty test section airspeeds to reach over 240 miles per hour. In addition, a new dual-loop heat exchanger was added to limit air temperature rise in the tunnel during sustained higher speed tests. The Beech Wind Tunnel is the only commercial wind tunnel on a university campus in North America that has active heat removal which allows it to run all day long, all week long without heat build up that degrades aerodynamic performance. A new six component, under-floor pyramidal type external balance was also added that has the highest load range and resolution of any balance in the world for this application. It can detect a minute change of aerodynamic load on a wind tunnel model, yet measure a large load.

The National Institute for Aviation Research has responded to the needs of the aviation community with the upgrade and modernization of the Beech Wind Tunnel. This facility is well poised to support the aerodynamic research needs of industry and academia in the many years to come.

17. Key Words

Wind tunnel, aerodynamics, National Institute for Aviation Research, NIAR

18. Distribution Statement

This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F1700.7 (8-72) **reproduction of completed page authorized**

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EXECUTIVE SUMMARY

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1. PROJECT BACKGROUND.

Designed and constructed in the late 1940s, the Walter H. Beech Memorial Wind Tunnel (Beech Wind Tunnel) was built as a response of the local aircraft companies, namely Beechcraft and Cessna Aircraft companies. These companies needed an aerodynamic research facility nearby to support the ever expanding market for aviation products. Mr. Ken Razak and the University of Wichita responded and constructed the University of Wichita 7 x 10 Low Speed Wind Tunnel using funding from Beech, Cessna, the University of Wichita, and the Kansas Industrial Development Commission. Low cost concrete and many war surplus parts were used to obtain a working wind tunnel on a small budget.

The wind tunnel was dedicated to the memory of Walter H. Beech, aviation pioneer and founder of Beechcraft Company, after he passed away in 1950.

This wind tunnel served the aerospace community well for the next decades with improvements in equipment and apparatus over the years. These improvements include the replacement of the original Allison gasoline engines with a 1,000 horsepower electric motor and upgrades to the sensor and computer technology over time.

Eventually, the electric motor (which was surplus in 1952), the World War II-era propeller, and the external balance, and many other components were showing great signs of wear and the performance of the tunnel degraded. The degradation was great enough that the Beech Wind Tunnel could no longer provide the data quality that the local aircraft companies were asking for. A major upgrade and modernization of the Beech Wind Tunnel was absolutely necessary if it was to regain its position as a key aerodynamic research facility for the aviation companies of Wichita.

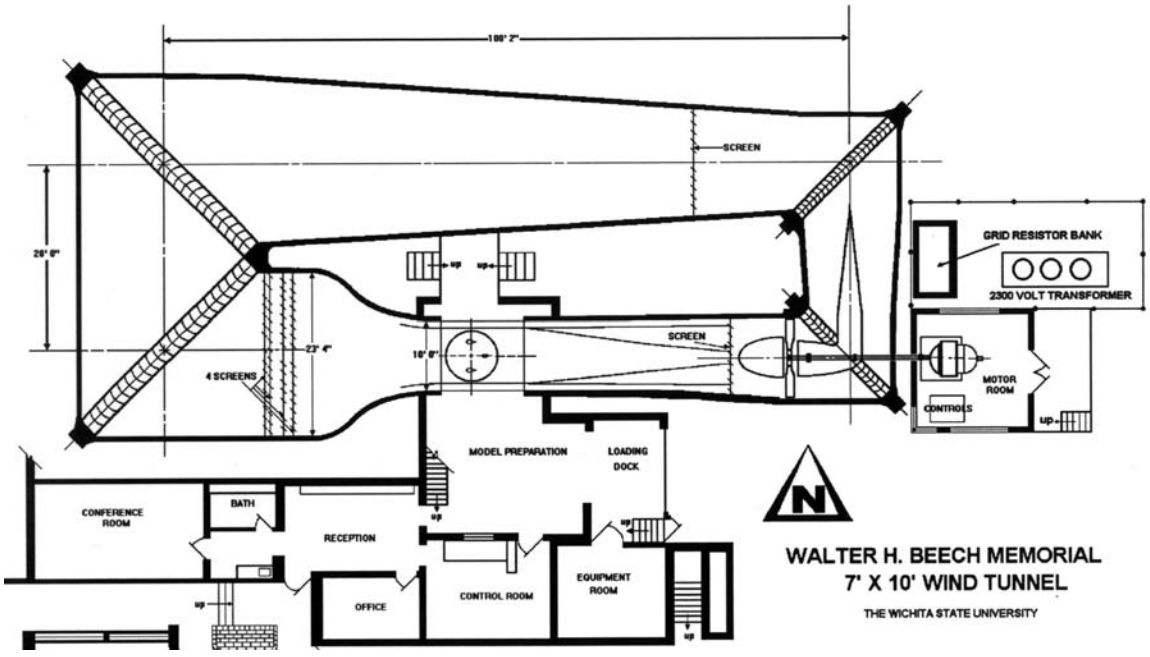

FIGURE 1: WALTER H. BEECH MEMORIAL WIND TUNNEL 1948-2003

2. PROJECT DESCRIPTION – STATEMENT OF NEED.

The Beech Wind Tunnel is the landmark facility of the Aerodynamic Laboratories of the National Institute for Aviation Research (NIAR) on the campus of Wichita State University (WSU). Planning for the Upgrade and Modernization of the Beech Wind Tunnel began with extensive interaction with the NIAR Advisory Board, the NIAR Aerodynamics Laboratory Advisory Board, past and current clients, and academic advisors from the WSU College of Engineering Aerospace Engineering Department. A copy of the proposal to the Federal Aviation Administration is included as Appendix A.

The focus of the upgrade and modernization of the Beech Wind Tunnel was on the performance fundamentals of the facility. Specifically, it needed higher and improved performance in the test section. The air speed needed to be improved from 150 mph to over 200 mph in order to more closely match desired test conditions. In addition, a heat exchanger was needed to remove the heat build-up from fan inefficiencies and friction build up from the fast moving air. New flow conditioning devices were also required in order to maintain or preferably improve the flow quality in the test section in terms of flow angularity, uniformity, and turbulence intensities.

The other fundamental that must be addressed is the external balance. Designed, fabricated, and built by faculty and staff from the University of Wichita Engineering Department, the external balance served well as the tunnel's primary means of data gathering for over 50 years. See Figure 2 below. It was upgraded with the times over the years with the addition of new sensors and computer data acquisition equipment. It did, however, reach the end of its useful life in terms of supplying the data resolution that the aerospace researchers were demanding. A new external balance was necessary in order to provide the data quality that was able to be obtained with the improved tunnel performance.

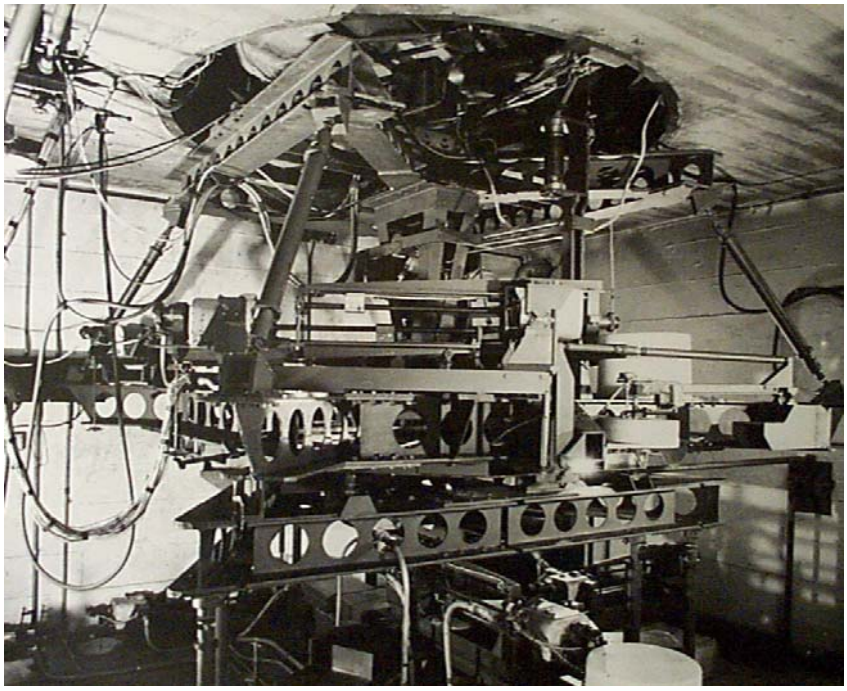

FIGURE 2: EXTERNAL BALANCE

Other areas of the Upgrade and Modernization Program were not focused on the fundamental issues with the facility, but were no less important. They included a completely remodeled and rebuilt test section and a new and remodeled control room.

3. UPGRADE AND MODERNIZATION PROGRAM – TECHNICAL OBJECTIVES.

Since the Upgrade and Modernization Program focused on the fundamentals mentioned above, the technical requirements were split into two Request for Proposals (RFP). NIAR recognized early in the Program that there are two distinct disciplines of wind tunnel supply companies – ones that specialize in wind tunnels, and ones that specialize in wind tunnel external balances. A copy of RFP for the Tunnel Circuit is included in Appendix B.

3.1 TECHNICAL OBJECTIVES – TUNNEL CIRCUIT.

The technical objectives of the Tunnel Circuit of the Upgrade and Modernization of the Beech Wind Tunnel focused on improving and obtaining higher performance of the air flow in the test section of the wind tunnel. The details of these can be reviewed in Appendix B. A summary of the test section requirements is shown below in Table 1.

TABLE 1: TEST SECTION TECHNICAL REQUIREMENTS

Parameter	Technical Requirement/Target	Comments
Reynolds Number	Re>1.8M/ft for T<110ºF	Re>1.5M/ft with CdS=5.6 ft²
Dynamic Pressure Range	0.5 psf < q < 100 psf	Lower end range may be impractical with closed loop control
Temperature	Tmax < 110ºF	At q=100 psf for 8 hours of continuous operation
Dynamic Pressure Uniformity	$\Delta q/qave$ <0.5%	1σ specification
Dynamic Pressure Stability	$\Delta qref/qref$ < 0.5%	1σ specification
Flow Angularity	$\Delta\alpha,\Delta\beta$ < 0.2º	1σ specification
Turbulence Intensity	u'/U,v'/V,w'/W < 0.25%	An average of five measurements in a plane

Three companies were sent RFP packages along with the RFP posted for public response: Aero Systems Engineering, Inc., Aiolos Engineering Company, and Jacobs-Sverdrup. The RFP from NIAR and Wichita State University asked for a Rough Order of Magnitude (ROM) cost estimate to be included with the proposal. Two of the three respondents did supply a ROM. Jacobs-Sverdrup was the only respondent that supplied a ROM, but it included a large contingency sum to account for the several unknowns included with the scope of the project. Jacobs-Sverdrup proposed and the University accepted a $135k, 4-month long contract to conduct an Engineering Study of the Upgrade and Modernization of the Walter H. Beech Memorial Wind Tunnel. The goal of this study was to examine in detail the appropriate measures to employ to bring the existing facility to the requested performance and to significantly reduce the contingency costs. A copy of Jacobs-Sverdrup's proposal response and their proposal to provide an Engineering Study is included as Appendix C.

Although the one of the goals of the Engineering Study was to reduce unknown contingency costs, actual budget estimate costs increased as further investigation discovered additional areas not originally accounted for in the initial response by Jacobs-Sverdrup. A copy of the final report from the Engineering Study is included as Appendix D. Highlights of the major conclusions of the Engineering Study include:

- Removal of the existing fan, nacelle, and drive shaft components in Corner 1 of the wind tunnel and replacement of the affected turning vanes.

- Installation of a new Foreign Object Damage (FOD) screen in front of the turning vanes in Corner 2.

- Removal of approximately 33 feet of existing tunnel ducting in the backleg of the wind tunnel and installation of a new fan system assembly to provide propulsion for the wind tunnel.

- Installation of a dual-loop heat exchanger in front of the existing Corner 3 turning vanes. Included with this is all piping, pumping, secondary heat exchanger, and cooling tower.

- Installation of flow conditioning elements after Corner 4 in the settling chamber of the wind tunnel. These elements include a honeycomb flow straightener and a spring-tensioned anti-turbulence screen.

- Addition of access hatches around the circuit to enable maintenance access by tunnel personnel.

- Erection of a new equipment building to house the heat exchanger pumps and secondary heat exchanger, and to also house the electronic Variable Frequency Drive (VFD) for the new fan assembly.

Upon completion of the Engineering Study, Jacobs-Sverdrup was awarded the final contract for the tunnel circuit portion of the project.

3.2 TECHNICAL OBJECTIVES – EXTERNAL BALANCE.

The technical objectives of the External Balance of the Upgrade and Modernization of the Beech Wind Tunnel focused on improving and obtaining higher performance of the external balance of the wind tunnel. The details of these can be reviewed in Appendix E.

A summary of the major technical requirements of the external balance is shown below in Table 2.

TABLE 2: EXTERNAL BALANCE TECHNICAL REQUIREMENTS

Balance Component	Design Load or Moment	Minimum Resolution
Normal (lift)	± 2,000 lbs.	0.4 lbs.
Axial (drag)	± 800 lbs.	0.04 lbs.
Side Force	± 1,000 lbs.	0.4 lbs.
Rolling Moment	± 40,000 in-lbs.	5.0 in-lbs.
Pitching Moment	± 10,000 in-lbs.	0.7 in-lbs.
Yawing Moment	± 10,000 in-lbs.	0.5 in-lbs.
Balance Accuracy	± 0.02% Full Scale Load or Moment (all components)	
Yaw Motion	300º @ 2º/sec	
Pitch Motion	± 45º @ 2º/sec	

Three companies responded to the RFP for the Upgrade and Modernization of the External Balance: Aerotech ATE, Ltd, Allied Aerospace, Inc, and Shenck-Pegasus Corp. After a rigorous selection process, Aerotech ATE, Ltd. was awarded the contract for the Upgrade and Modernization of the External Balance for the Walter H. Beech Memorial Wind Tunnel. A copy of Aerotech's response is included as Appendix F and G.

Aerotech proposed a replacement external balance that closely matched the design of the then current balance. In addition, Aerotech showed the greatest resolution of the three respondents based upon supplied calibration data of a like-designed balance in recent history.

4. UPGRADE AND MODERNIZATION PROGRAM – TECHNICAL RESULTS.

The results of the Upgrade and Modernization of the Walter H. Beech Memorial Wind Tunnel successfully met with the requirements set out at the start of the project. All parties involved in the project performed at or above the level of the technical objectives.

4.1 TECHNICAL RESULTS – TUNNEL CIRCUIT.

The results of the Tunnel Circuit Upgrade and Modernization of the Walter H. Beech Memorial Wind Tunnel are again in line with the requirements specified in the original RFP.

The requirements for the Upgrade and Modernization of the Tunnel Circuit were focused on higher and improved performance of the air flow in the test section. As this project was in essence a major remodeling of an existing facility, Jacobs-Svedrup would not warrant performance issues physically tied to the existing facility, namely flow quality. Jacobs-Sverdrup did guarantee the performance of the following items:

- Maximum Test Section Air Speed
- Maximum Test Section Air Temperature Rise

All other flow quality performance parameters were contracted as targets, not guaranteed performance. This is due to the fact that several limiting factors affecting the flow quality are "cast in concrete" with the existing shape of the wind tunnel. The costs to change the shape of the tunnel would have become prohibitive to the point of demolition of the complete facility and starting over with a new one.

A plan view of the completed tunnel circuit is shown below in Figure 3:

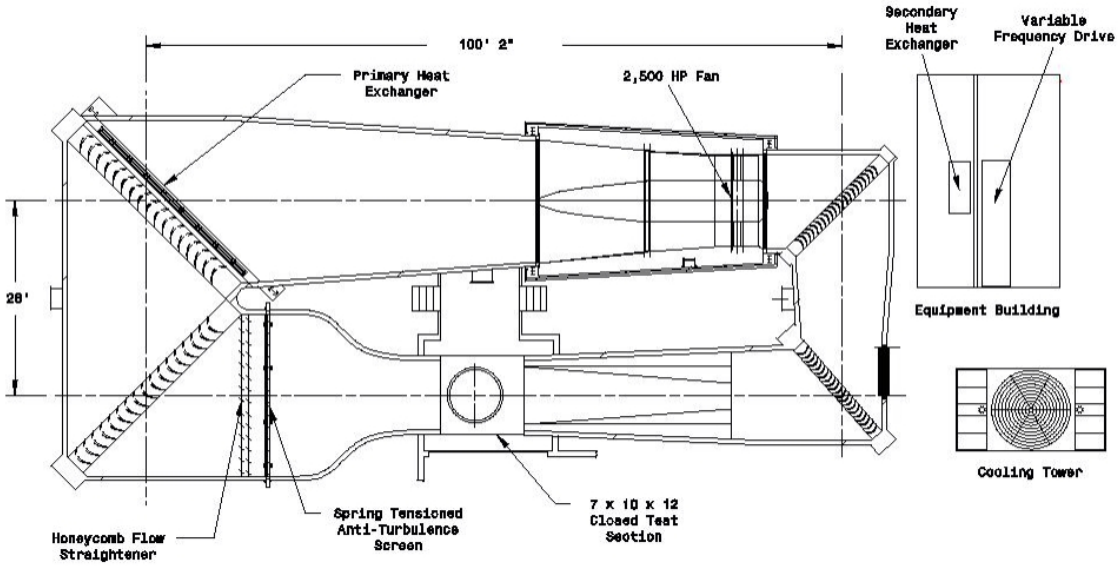

FIGURE 3: NEW TUNNEL CIRCUIT PLAN

The new tunnel circuit design is focused on the fundamental requirement of improved and higher performance test section performance. The new fan assembly, the heat exchanger, and the new flow conditioning elements all contribute to the improvement and increased performance of the test section air flow. A summary of the results compared to requirements is listed below in Table 3.

TABLE 3: TEST SECTION TECHNICAL RESULTS

Parameter	Technical Requirement/Target	Observation
Reynolds Number	Re>1.8M/ft for T<110ºF	1.93 M/ft
Dynamic Pressure Range	0.5 psf < q < 100 psf	133 psf (empty) 103 psf (with blockage)
Temperature	Tmax < 110ºF	Have yet to observe Ts > 95ºF
Dynamic Pressure Uniformity	Δq/qave <0.5%	Δ_{Cq} average = 0.695%
Dynamic Pressure Stability	Δqref/qref < 0.5%	Δ_q average = 0.25%
Flow Angularity	Δα, Δß < 0.2º	$\Delta\alpha_{ave}$ = 0.07º $\Delta\beta_{ave}$ = -0.4º
Turbulence Intensity	u'/U,v'/V, <0.25%	$(u'/U)_{ave}$ = 0.10% $(v'/V)_{ave}$ = 0.18%

The technical requirements for the Upgrade and Modernization Project were successfully met as a result of the contract. The target goals for the upgrade were quite satisfactorily addressed and are very acceptable. The Upgrade and Modernization of the Walter H. Beech Memorial Wind Tunnel can be considered a tremendous success in terms of both technical requirements reached and technical goals satisfactorily met.

4.2 TECHNICAL RESULTS – EXTERNAL BALANCE

The results of the External Balance portion of the Upgrade and Modernization Program are again successfully addressed with the requirements set out at the start of the project. Aerotech ATE, Ltd. performed at and above the requirements set out for the external balance.

The requirements for the External Balance were such that the existing balance had to be replaced. Aerotech proposed and designed a brand new, custom designed balance for the Beech Wind Tunnel. This balance is a six component, pyrimidal, truncated prism, underfloor balance. In order for this new balance to be installed in the balance room basement of the wind tunnel, access had to be provided through the test section floor for the new balance. A photo of the new balance is shown below in Fig. 4

FIGURE 4: NEW AEROTECH ATE, LTD. EXTERNAL BALANCE

The results of the External Balance project of the upgrade and modernization project are listed below in table format in Table 4.

TABLE 4: EXTERNAL BALANCE TECHNICAL RESULTS

Design Parameter	Requirement	Result
Normal (lift)	± 2,000 lbs. Range	± 1984 lbs.
	0.4 lbs. Resolution	0.079 lbs. (0.002% FS)
Axial (drag)	± 800 lbs. Range	± 794 lbs.
	0.04 lbs. Resolution	0.032 lbs (0.002% FS)
Side Force	± 1,000 lbs. Range	± 1984 lbs.
	0.4 lbs. Resolution	0.079 lbs. (0.002% FS)
Rolling Moment	± 40,000 in-lbs. Range	100,680 in-lbs. (total)
	5.0 in-lbs. Resolution	2.0 in-lbs (0.002% FS)
Pitching Moment	± 10,000 in-lbs. Range	20,136 in-lbs. (total)
	0.7 in-lbs. Resolution	0.408 in-lbs. (0.002% FS)
Yawing Moment	± 10,000 in-lbs. Resolution	19,620 in-lbs. (total)
	0.5 in-lbs.	0.396 in-lbs. (0.002% FS)
Balance Accuracy	± 0.02% Full Scale Load or Moment (all components)	± 0.02% Full Scale Load or Moment (all components)
Yaw Motion	300º @ 2º/sec	+210º/-150º @ 2º/sec
Pitch Motion	± 45º @ 2º/sec	± 45º @ 2º/sec

The requirements for the Upgrade and Modernization of the External Balance were focused on an increased load range and increase in resolution and sensitivity performance. One can observe from the above table that the requirements for the External Balance were met or exceeded for each requirement.

5. CONCLUSIONS.

The Upgrade and Modernization of the Walter H. Beech Memorial Wind Tunnel has been a tremendous success. All major and pertinent requirements and goals set out by the Project have been met. The NIAR and WSU have provided industry, academia, and other interested parties a state-of-the-art wind tunnel for less than half the cost of a brand new wind tunnel. The Walter H. Beech Memorial Wind Tunnel is well poised and on-line to serve the aviation and related communities.

APPENDIX A: FAA PROPOSAL

APPENDIX B: REQUEST FOR PROPOSAL – TUNNEL CIRCUIT

APPENDIX C: PROPOSAL TO PROVIDE ENGINEERING STUDY ON TUNNEL CIRCUIT UPGRADE

APPENDIX D: ENGINEERING STUDY FINAL REPORT AND UPGRADE PROPOSAL

APPENDIX F: PROPOSAL FOR UPGRADE OF EXTERNAL BALANCE