Report

of the

NSF Cost/Management Review Panel

for

ALMA North America

Performed for the
National Science Foundation

Conducted at NRAO in Charlottesville, VA
from January 30 - February 1, 2006

February 23, 2006

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National Radio Astronomy Observatory
Charlottesville, VA

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Executive Summary

A site visit to carry out the baseline cost/management review of the North American ALMA project (ALMA NA) was conducted by a panel of experts on behalf of the National Science Foundation on January 30 – February 1 at the National Radio Astronomy Observatory (NRAO) in Charlottesville, VA. The review covered all aspects of the proposed project. The ALMA NA project is part of the International ALMA project being constructed on the Chajnantor altiplano in northern Chile. The ALMA NA project managed by NRAO through AUI is an equal partner with the European Southern Observatory (ESO) in ALMA. The scientific merit of the proposed project was reviewed favorably by both the confidential NSF review process and by astronomical decadal survey where it received the highest priority for future projects. Recently, a National Research Council panel concluded that the project would provide transformational results for astronomy.

The Panel was asked in the charge for the review to:

• Validate the cost, schedule and funding profile of North America's share of ALMA construction.

• Validate the ALMA operational concept and cost.

• Validate the ability of AUI/NRAO to complete the construction of ALMA successfully for NA based on its heritage and ownership of the ALMA concept, and performance in ALMA to this point.

• Review ALMA's construction cost growth and confirm that these costs are now fully understood.

While it is impossible during the course of a three day review of a project of this scale to probe every aspect of the project, five areas (Independent Project Teams (IPT)) were examined in some detail. These were the Management IPT, the Site IPT, the Antenna IPT, the Back End Electronics IPT, the Computing IPT, and the Systems Engineering and Integration IPT. The remaining areas consisting of the Front End Electronics IPT, the Correlator IPT, and the Science IPT were looked at in less detail but with sufficient depth to assess their likelihood of being successfully completed. After listening to the presentations and discussing the details with the project teams in the breakout sessions, the Panel concluded that the project costs are understood and that the schedule while tight can be met with careful management. The ALMA NA project needs to develop more centrally managed contingency within the new baseline total project cost in order to assure completion of the project within the new baseline total project cost. The proposed funding profile needs to be maintained if the project is to be constructed for the new baseline cost.

The operational plans for ALMA are at an early conceptual stage and will need considerably more work before a solid cost estimate can be developed. The initial cost estimates presented to the Panel seemed to be reasonable. The transition to operations will

need careful attention so that science can begin as early as possible to capture the maximum benefit from the large investment in ALMA. After a small number of antennas are in place and commissioned, it will be the world's best millimeter wave observatory and can provide early glimpses of the observations to come when the array is complete.

The new management of the North American part of the ALMA project appears to be functioning well. All the players, AUI, NRAO, the NSF, JAO, and ESO, must pay careful attention and continue to work together to maintain effective management in order for the ALMA project to be completed successfully.

The construction cost growth of the ALMA project is understood and is detailed in the management section of the report.

Is the project organized, staffed, committed, and positioned to complete the ALMA NA project within the proposed new baseline? The answer to the best of our judgment is "yes." The summary observations given below have been ordered to reflect the opinion of the Panel that the first ten items are going well and the last ten items will require careful attention. With this in mind, the Panel recommends that the National Science Foundation go forward with the project. After approval of the project, the Panel recommends an in-depth review of the project every six months to insure its timely completion within the agreed scope, schedule, and cost.

The following summary observations were formulated by the ALMA NA Cost/Management Review Panel and presented at the closeout of the review in Charlottesville. The first ten observations seem well in hand while the last ten observations will need careful attention by ALMA NA.

1. In the complex environment that the ALMA project is working in, delivery performance of the partners is crucial to the success of the project. The management structure that is in place gives confidence that the needed performance level will be met.

2. The ALMA project management structure has made significant progress in reducing the delay for making high level decisions (as evidenced by resolution of the antenna testing problems and the Chilean local hiring issue).

3. The Site IPT project manager is living in San Pedro and is using his knowledge of the local construction environment to select the best suite of bidders for site projects. This should significantly reduce the chance of avoidable cost escalation in this critical area.

4. Both antenna fixed-price contracts have been placed removing a large uncertainty in the total project cost. The parameters of the contract with Vertex were examined in some detail and do not raise any undue concerns.

5. Nearly all correlator components have been ordered and one quarter of this key element has been in operation for nearly one year. The rebaselined cost of this IPT is less than the original budget estimate and is on track.

6. The initial operation at the site of the APEX antenna (a nearly identical version of the ALMA antenna) manufactured by Vertex has demonstrated the pointing accuracy and a surface accuracy significantly exceeding ALMA specifications.

7. The technical readiness of the project is very high and construction is under way.

8. The level of talent of the ALMA team is very high.

9. The project has reduced the number of antennas from 64 to 50 as part of the response to this cost increase.   The scientific impacts have been studied by an NRC committee which concluded that ALMA would still be capable of transformational results.

10. The two antenna designs currently on order may provide opportunities both in antenna acquisition and in the understanding of systematics.

11. The current project management structure is working well and must continue to do so in order to deliver the project on cost and schedule. The qualifications and commitment of the current team provide the best assurance that this situation will continue.

12. The PCMS is just beginning to give data. It is essential that this critical management tool be working initially by the end of March 06 and be used aggressively as a management tool as soon as possible.

13. The level of contingency remains a concern. Every effort needs to be made to increase this without increasing the current estimated total project cost. The project has begun an approach that would lead to a contingency in the 25 to 30% range which would give high confidence for on-cost completion.

14. Contract monitoring and supplier management need to be carried out carefully to avoid cost escalation.

15. The project should take advantage of the lessons learned from analyzing the cost increase to insure that its management systems are sufficiently robust to prevent any future cost increase.

16. The performance metrics and tracking tools developed by the computing IPT are an effective management device in an area that is traditionally difficult to monitor. They should endeavor to anticipate and correct for problems early.

17. The quantity and mix of electronic hardware deliverables to Chile is high. This area requires close attention to detail including inventory control and logistics.

18. The assembly of hardware at the high site is recognized as a challenge. All effort should be made to have this be made as simple and straightforward as possible. Safety in this environment must receive the highest priority.

19. JAO and the project engineer need to take charge of system engineering as an ongoing functioning tool. System engineering of the overall system may provide opportunities for cost savings, increased reliability, and reducing risk by trading performance specifications among system components and still achieve overall system performance.

20. The risk register presented by the project manager provides a cross check of the contingency analysis and if used routinely will be an important management tool.

Introduction

The ALMA Project is an international radio astronomy project led and managed by two equal partners: North America (NSF and NRC-Canada as funding agencies with NRAO as executor) and Europe (ESO and Spain collaborating with ESO as executor). Its original planning and baseline cost was developed around 2000. ALMA is being built in Chile near the border with Argentina and Bolivia on a high, dry plain at an altitude of 5,000 meters. Chile is an ALMA partner hosting the site, but providing no funding. Details of the formal partnership agreement are being finalized with Japan, and negotiations are currently underway with Taiwan about joining the North American project. Taiwan already has an agreement with NAOJ. A two-party Memorandum of Agreement is in place between North America and Europe, along with additional agreements with the other participating countries. The equal-partner agreement gives both parties equal voice in project governance and equal responsibilities for project funding.

The funding split between the parties is based on the baseline cost estimate (in FY2000 "Y2K" dollars) and assigns to each party responsibility for providing specific, identified scope valued at half the total cost. No adjustment between parties is to be made if the actual price varies from the estimated value. The use of Y2K dollars avoids value complications that would be caused by cost escalation and exchange rates.
Over the past two years, talented, dedicated, and experienced individuals have been hired into key ALMA positions by both ESO and NRAO. The ALMA Board and advisory committees are in place and functioning. Project management systems are in place and operating, with earned value reports expected to be available in March 2006.
The two large antenna contracts, representing close to half of the ALMA budget have been placed. The antenna contracts, however, are for a price very substantially higher than estimated in the original baseline. This situation, along with other cost experience and information, made it clear last year that ALMA could not be built for the original baseline cost estimate.

Since then, the project has undertaken a substantial rebaselining activity to review and re-estimate costs and schedules. To minimize the cost overrun, the project is proposing to reduce the ALMA array size from 64 to 50 antennas, a reduction judged by a National Research Council committee to leave ALMA still capable of performing transformative scientific research. Even with this reduction in scope, the new estimated cost to complete the project significantly exceeds the approved baseline. Thus, the project is requesting its sponsors to approve a new baseline, based on the new cost estimate and schedule. The project has also proposed adjustments to the scope assigned to each Party, so that the new baseline is divided equally by value and they each cover half of the projected cost increase.

Panel Methodology

Written material provided in electronic form by the ALMA NA project to the Panel in advance of the meeting was examined and oral presentations were heard. Subgroups of the Panel met with appropriate members of the ALMA NA project team to explore details of the project. The format of the review followed the pattern of reviews of other large projects with roughly equal times devoted to overview presentations followed by expanded breakout sessions with individual groups for in depth discussions. This arrangement provided a very effective format for the review of a proposed project of this scale. Based on these evaluations, the Panel discussed its findings in executive session and generated the written summary conclusions and observations that were given above. Details of the assessment of the proposed ALMA NA project follow.

1.0 Management

This section addresses two of the four charges to the Panel:

- Validate the ability of NRAO/AUI to complete the construction of ALMA successfully for NA, based on its heritage and ownership of the ALMA concept, and performance in ALMA to this point.

- Review ALMA's construction cost growth and confirm that these costs are now fully understood and contained.

Based on its interactions, the materials presented by the project, and management's responses to its questions, the Panel believes that the NRAO/AUI is likely able to complete the construction of ALMA successfully for North America. While the Panel recognizes several issue areas, detailed below, the Panel believes that these can be addressed if managed aggressively.

The growth in ALMA's construction costs was probed extensively by the Panel. Based on the information provided, it appears that the root causes are understood by the project and have been addressed by changes in key personnel, processes, and policies. Therefore, the Panel believes that past cost overruns do not indicate future overruns, and that the project is likely to contain these going forward.

1.1 Ability of NRAO/AUI to Complete Construction of ALMA Successfully for North America

NRAO has a long history of significant contributions to the astronomical sciences. It manages several observatories, including Green Bank, the Very Long Baseline Array, and the Very Large Array, which is the most productive ground-based astronomical instrument in the world. NRAO has made significant contributions to the education and mentoring of several generations of astronomers. Furthermore, the NRAO has consistently pushed the technological envelope in the development of data processing techniques, correlators, low-noise receivers, and state-of-the-art mixers and amplifiers, which have powered many cutting-edge experiments at NRAO and elsewhere.

NRAO was one of the founders of ALMA, having organized the original Millimeter Array (MMA) proposal. NRAO identified and characterized the future ALMA site in Chile and began the initial negotiations with ESO to form the ALMA project.

Today ALMA is well organized, well staffed, well documented, and well poised to proceed successfully within the proposed new baseline. Relationships among the international partners have been significantly improved, defined, and documented. Communication channels are functioning.

Talented, dedicated, and experienced individuals have been hired into key ALMA positions. Project management systems are in place and operating, with earned value reports expected to be available in March 2006. The antenna contracts, representing about half of the ALMA budget, have been placed by ALMA NA and ALMA Europe. The performance of the prototype antennas from both the manufacturers meets or exceeds the specifications. Furthermore, the APEX telescope, built by VertexRSI, the firm contracted by ALMA NA to build the antennas it is responsible for, has an antenna design very similar to the ALMA prototype. APEX has been operating successfully at the ALMA site for more than a year, giving further evidence that the plans are based on successful experience and should be achievable. Similarly, ALMA has successful prototypes or pre-production articles for several other key components, as described in other sections of this report. Moreover, the proposed baseline cost estimate has benefited from being developed in a responsible and systematic way and being subject to several cycles of intense internal and independent review.

Assessment of Current Management Ability

Management Talent

The level of management talent in the ALMA NA project and in the Joint ALMA Office (JAO) in Chile appears to be very high. The review materials were prepared well, presentations were clear, and Panel questions were addressed directly and satisfactorily. In particular, the North American project manager clearly took a top-management view while remaining knowledgeable in every detail probed by the Panel.

The management presentations and tools have evolved considerably beyond the level presented in the Garmisch review in October 2005, including:

- A clear analysis of the sources of cost increase, including a preliminary breakdown into root cause categories.

- Quantification of the risk register, including clearer ownership of risks, a breakdown by North American and European risks, and comparison to budgeted contingencies.

Most IPT leaders are seasoned practitioners and managers. They demonstrated a clear vision of their aspect of the project as well as a clear grasp of the details required for success. Very few, however, are members of groups traditionally underrepresented in science and engineering in the USA.

Organizational Structure of the ALMA Project

Top-level Organizational Structure of ALMA

ALMA has the burden of creating a new model for major scientific facilities partnerships in which there is no lead or primary owner. Because of the equal international ownership and control and the flow of funds to each sponsor's implementer, certain aspects of the organization may appear to be unusual. For example, the overall ALMA Director (Tarenghi) does not directly control any budget. He is, nonetheless, responsible for the success of the overall ALMA Project.

The ALMA Director reports to the ALMA Board, which has representatives from ESO, NSF, NRAO, Chile, Canada, Japan, and some distinguished members of the astronomical community from Europe and North America. The Director is located at and leads the JAO in Santiago, Chile, and he supervises the JAO Project Manager. The JAO project manager supervises the two project managers in North America and Europe, who are responsible for the funding provided respectively by their sponsors. These project managers are simultaneously accountable to their organizations (respectively NRAO and ESO) and to their primary sponsors (respectively NSF and ESO). The JAO is funded equally by both Parties.

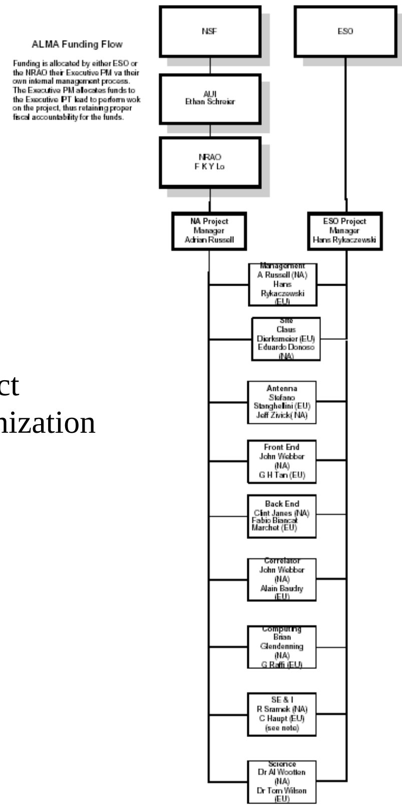
Although these arrangements appear complicated and cumbersome, this Panel, when it understood them, was impressed and judged them to be important for the successful management of ALMA. It was very helpful that the ALMA Director and JAO project manager attended and participated fully in this review of ALMA NA. Furthermore, the project has taken significant steps over the last year to improve the workability of this arrangement by strengthening the JAO, as needed to ensure it has the influence and leverage needed to fulfill its role:

- Jointly employing JAO officers by both executives. This arrangement makes it possible for JAO personnel to act for and on behalf of both parties to the ALMA agreement.

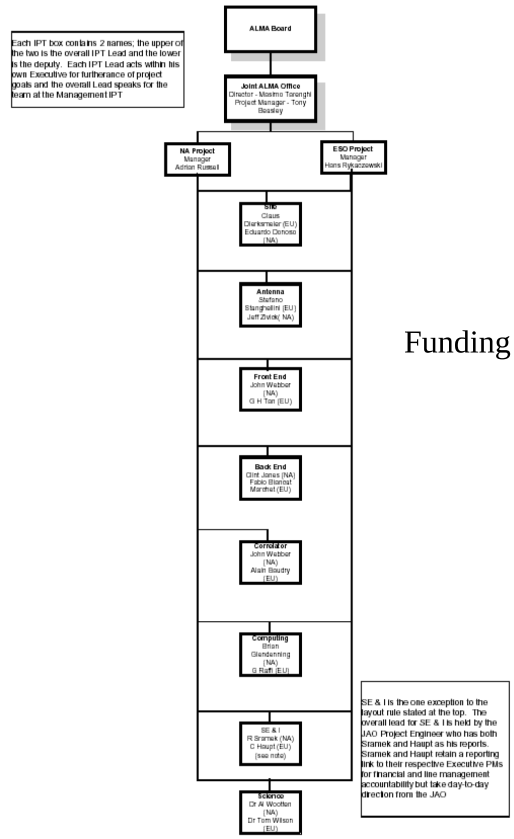
- Clarifying lines of authority for JAO officers and for the North American project manager:

    - The JAO Director reports directly to the Board.

    - The JAO project manager has the project technical leadership role, making him directly responsible for all technical decisions of the project.



Project
Organization



Funding Flow

- The North American project manager has made the creation of a good working relationship with the JAO project manager a formal personal performance goal, which will be used by the NRAO director as an annual performance evaluation criterion.

- Requiring authorization from the JAO director for expenditures over $500K. This mitigates the lack of budgetary authority of the JAO by making it a required partner in significant budgetary decisions.

- Making the decision to hire new JAO staff as employees of one partner (AUI), while ensuring their loyalty to the ALMA Project overall, rather than to one partner.

The Panel saw evidence of the effectiveness of this strengthened management arrangement. For example, once the JAO project manager restarted the evaluation of the antenna prototypes in December 2004, all testing was completed satisfactorily for both antenna designs within about 3 months, a remarkable achievement for such complex systems.

Management Structure of AUI, NRAO, and the Role of the North American Project Manager

The North American project manager reports to the NRAO director, who in turn reports to the President of AUI. Legal responsibility for ALMA NA is assigned to AUI, through the Cooperative Agreement between NSF and AUI, which provides the funding. Personnel working on ALMA NA (including the ALMA NA project manager) are hired by and assigned to ALMA by NRAO. ALMA is effectively one division of NRAO, albeit a very large one. When ALMA is an operating observatory, its North American component will continue to be managed as a division of NRAO.

The Panel considers this organizational arrangement to be effective, as it ensures that ALMA receives optimal support from NRAO, in terms of key managerial and technical personnel, intellectual property, laboratory equipment, working space, and administrative support. Because the ALMA Project is part of NRAO, its performance and success is a formal responsibility of the NRAO Director. Thus, the professional success of the Director of NRAO depends on ALMA's progress and success. This arrangement gives the NRAO Director direct incentive to support ALMA in the competition for scarce resources and essential expertise within the NRAO organization. If the ALMA-NA project manager reported directly to AUI, this incentive and relationship would be weaker, and the AUI President and/or Board could be in the position of having to intervene frequently to broker resource allocation. This organizational arrangement has the further advantage of positioning ALMA favorably for the transition from construction and commissioning to operations and science.

IPT Management Structure

The IPT management structure appears to work well. Each IPT has two leaders, one from North America and one from Europe. This arrangement forces the major partners to collaborate on the system, and minimizes the potential for mismatches and disconnects as the work proceeds. To minimize decision making difficulties, the project has chosen one person as lead and one as deputy for each IPT. Furthermore, technical scope and project responsibilities are clearly divided among IPTs through use of a detailed Work Breakdown Structure (WBS). Each WBS element is the responsibility of only one of the major ALMA partners.

Management Systems

The Panel assessed the project's management systems in some detail, and considers them to be effective, especially once Earned Value reporting has commenced:

- The ALMA top management appears to have established open and effective lines of communication and performance management:

  Weekly scheduled conference calls between the President of AUI, the NRAO director, and the ALMA-NA project manager allow issues to be aired and discussed in a timely manner. ALMA budget, schedule, (and soon, Earned Value) reports are reviewed by the NRAO director on a monthly basis. The project manager has clear performance goals, and his compensation is variable to reflect his achievement level.

These North American calls are supplemented by weekly calls of the NRAO director, the ESO Director General, the ALMA project manager, and the JAO director. Cost, schedule (and soon, Earned Value) reporting is aggregated across the entire project by the JAO on a monthly basis, serving as a foundation for reporting to the ALMA Board. The Panel noted the emphasis placed by all parties, JAO director, NRAO director, and ALMA NA project manager, on their commitment to work collaboratively.

• The management system for the IPTs appears effective as well. The ALMA NA project manager holds monthly reviews of each IPT, assessing costs, action items, milestone completion, and Earned Value once available. Interfaces between IPTs are identified, with the majority defined and frozen.

• Technical changes, a traditional driver of project costs and schedule, appear well-managed. The project has introduced a Configuration Control Board (CCB), which includes the JAO, the North American and European project managers, a science representative, and the Japanese project. The CCB has to approve all technical changes that transcend IPTs, and considers the cost and schedule implications of any such change. Final approval of all changes resides with the JAO director.

• Earned Value reporting will be an important component of the management system of the project. However, this is still in the process of being implemented and will not be available until March 2006.

• Risk management has made significant progress with the creation of a unified risk register, in which risks are identified and quantified at the IPT level, with owners and mitigation actions. At the IPT level, this risk register is reviewed monthly. At the North American project manager level, the risk register is reviewed on a quarterly basis.

Cost and Schedule

Assuming decisions can be made in a timely and informed manner, this Panel judges the proposed new baseline cost estimate to be sound and appropriate for this stage of the project. The cost estimate has benefited from being developed in a responsible and systematic way. Similarly, the schedule has been built bottom-up, and it is based on significant experience. Furthermore, the new cost estimate and work plans have been subjected to several cycles of intense internal and independent review, of which the present review is the latest.

The Panel was asked to focus on the North American scope, budget, and schedule. In our judgment, the cost estimate for the North American scope looks reasonable: neither excessively generous nor impossibly tight. However, the overall ALMA NA project contingency appears to be too low for this stage of the project. The schedule has some float built into milestones and work plans throughout the project. There appears to be very little schedule float at the end of the project.

Since the total cost of ALMA NA is a project parameter that must be explicitly approved by the NSF Director, the National Science Board, and the Congress, the project must ensure that under no circumstances will it be overrun. To be able to make this assurance, the project needs now to increase overall project contingency, without increasing the current estimated total project cost. If on-time completion is similarly a non-negotiable requirement, prudence suggests placing several months of float at the end of the project.

During the review, the ALMA NA project manager initiated a process that would lead to a contingency in the 25% to 30% range (as a fraction of unspent and unobligated funds). A contingency in this range would give high confidence for on-cost completion. The way the project is doing this is by identifying the cost margin in each IPT cost estimate, and ensuring that the adjusted baseline budget for each IPT is sufficient to accomplish the scope under favorable conditions. The margin that would allow the IPT managers to cope with possible unfavorable conditions would be moved to the project contingency, where it can be managed centrally by the ALMA NA Executive.

For the schedule, the critical path includes antenna delivery. The fact that many antennas from the ESO contract are scheduled to arrive toward the end of the project means that there may be little that can be done within the ALMA NA schedule to move float to the end. Careful management and attention to schedule, plus early accomplishment of everything that can expedite installation and commissioning of the last antennas may be the best strategy. If on-schedule completion is as important to the sponsors as on-cost completion, the Panel suggests that the ALMA Project and NSF (and the European partners) consider adding 6 to 12 months of float to the Congressional completion milestone, while working aggressively to achieve the schedule presented.

Financial Reporting and Controls

Financial reporting is supported by the NRAO administrative group. The Panel did not conduct due diligence on the adequacy of reporting, but notes that NRAO's auditors, KPMG, reviewed how NRAO allocates directly associated costs to ALMA, and found those procedures to be reasonable and equitable. The Panel assumes that KPMG will issue an opinion on the adequacy of NRAO's accounting standards and controls as part of its regular audit cycle. This opinion should cover ALMA, since it is managed by NRAO.

Management Issues

While the current management of the ALMA project shows significant strengths, the Panel nonetheless feels that several areas merit close attention going forward.

Decision-making speed

Because the dual lines of funding flow are not aligned with the primary line of ALMA project management responsibility, and because the ALMA Director's authority is "weakened" because he does not directly control funding resources, the Panel felt there was significant potential for the Project to be handicapped by slow decision-making processes. Alternatively, the Board may have difficulties making potentially divisive decisions where the two Parties (NA and Europe) have very different views and preferences. In projects, delaying a decision (or worse, never making the decision) can often be worse than a sub-optimized decision, because it can cause schedules to drag out and costs to mount. The Panel believes that ALMA will need to implement governance and decision-making mechanisms that default to a decision (rather than to no decision) within a reasonable yet expeditious time.

Antenna Contractor Management

At a total value of $137 million in Y2K dollars excluding contingency, the contract with Vertex Communications for the 25 North American antennas constitutes the single largest expenditure of the project. Although the Panel did not see any significant issues with this contract, experience nonetheless dictates that the ALMA NA management pay close management attention to it. ALMA must avoid unnecessary change orders, track schedule milestones closely, be ready with technical advice and feedback, monitor quality during production, and be aware of any changes in the contractor's management attitude. This will likely require significant support from senior ALMA-NA management above the IPT level. At the same time, the project should consider co-locating engineering resources at the production facility to be involved during manufacturing and to build the relationships required to detect problems early.

Integration of New Partners into the ALMA Structure

New international partners, such as Taiwan, can bring additional resources to the Project, while making ALMA an even more international facility in operations. In high-energy physics, potential cost increases to the primary sponsors are often mitigated by acquiring new international partners whose financial or "in-kind" contribution offsets the cost growth or speeds facility completion. Alternatively, new international partners provide additional scope or features that extend the scientific reach of the facility.

Scientific access to ALMA—the world's one and only large facility for millimeter astronomy—when it is in full operation should be consistent with the fundamental principle on the use of major physics user facilities endorsed by the International Union of Pure and Applied Physics (IUPAP). This principle states that the institutional, regional, or national affiliations of the experimental teams should not influence the selection of an experiment or its priority. Selection and priority should be based on the following criteria:

a. scientific merit
b. technical feasibility
c. capability of the experimental group
d. availability of the resources required

Thus, it is valuable and important to welcome (even recruit) partners who would bring resources and expertise to the project. The project's current approach of having an explicit written agreement with new partners, integrating them into the management structure, and giving them a representative on the ALMA Board makes sense. Care must be taken to ensure that the integration of the new international partner does not bring unacceptable risks to cost, schedule, or baseline scope. It would also be desirable to have a time scale goal for finalizing the agreement and incorporating the new partner.

Cost and Schedule Confidence

The rebaselined project has a contingency of $32 million, which translates to a contingency of 18% for the uncommitted budget of $175 million, and 9% for the total project budget of $349 million. This level of contingency is low, and the project should increase it within the proposed total budget. The Panel believes that a contingency in the range of 25% to 30% of the uncommitted budget would give confidence that ALMA NA can be completed within the allocated funding. The ALMA NA Project Manager has initiated a process to increase contingency by moving some budget margin from the IPTs to the contingency fund. This process should conclude with a baseline cost estimate that is ready for presentation to the NSF Director and the National Science Board for their consideration.

The ALMA Board and its sponsors should decide how important it is for the project to achieve its completion milestone on schedule. If it is very important, the Panel recommends that the schedule be reviewed to place as much float as possible at the end. If, due to the contracted delivery schedule of antennas (or for any other reason), it is not credible to move work forward and place schedule float at the end, the Board and the sponsors should consider moving the official completion milestone to a later date (while encouraging the Project to finish on the current schedule). The Panel concurs with the conclusion of the Garmisch Review that keeping work on schedule is one of the best strategies for minimizing cost and achieving ALMA's transformational science capability as soon as possible.

In fact, ALMA's science capability can be used by the sponsors and the ALMA Board as a powerful incentive for the international project team to work quickly, carefully, and frugally. If, for example, it were allowed for the project to use unspent contingency to extend ALMA's science capability (for example by purchasing and implementing some of the antennas lost during the rebaselining), IPT leaders would strive to minimize their need for contingency. Without such an incentive, the normal project-execution psychology causes system managers to seek to minimize risks to their deliverables by requesting contingency as the first choice solution, whenever challenges develop.

Performance Management

The motivation and retention of leadership personnel is one of the largest determinants of ALMA’s success. Therefore, the ALMA Board, NRAO, and the North American project manager should consider a more proactive performance management approach. Elements of a performance management can include:

- Clear development objectives for individuals, translated into annual or semi-annual performance goals.

- Encouragement and rewarding of mentorship by peers and more experienced colleagues.

- Encouragement and rewarding of cooperation across IPT lines and among the main Partners.

- Support of intelligent risk-taking by individuals and IPTs.

- A more liberal use of financial (and non-financial) incentives, aligned with key project objectives and administered fairly and transparently.

A performance management system, especially the use of common and aligned incentives, can also serve as a mechanism for stabilizing complex reporting relationships (e.g., matrix reporting relationship of the North American project manager) that are currently founded primarily on goodwill. Explicit alignment of incentives in such situations is often used in complex, matrixed, organizations so that collaboration is maintained even if interpersonal relationships should become strained.

Risk Management

Although the project has adopted a risk register to identify and manage major risks, the Panel felt that risk management could be systematized and strengthened even further.

The project should consider adopting a risk burndown approach. In this approach, each risk receives a target resolution date. When aggregated, this results in a target risk reduction profile, which can be compared to the amount of actual risk retired over time. This can be used to manage risk at the IPT, the North American, and the JAO level.

International Dependencies

ALMA-NA represents half of the ALMA effort, and the AUI/NRAO/ALMA NA team does not have direct control over the performance of the European, Japanese, and other partners. ALMA, however, will not be a success and cannot enter full scientific operation until all parts of the project are delivered, integrated, and commissioned. This Panel cannot guarantee that other ALMA partners will deliver on their responsibilities. However, we can point to several factors and signs that mitigate against international dependencies derailing the project or causing the project to turn to NSF for additional funds.

• **Commitment and Visibility** -Peer pressure and national/regional pride are important forces that drive all partners to fulfill their ALMA obligations. The other partners are as fully committed to ALMA and its science as is the US, and the eyes of the world are watching the progress of this major facility. None of the partners wants to be seen as defaulting or as causing the Project's failure.

• **Governance Structures and the ALMA Board** -All partners, including NSF and AUI, are represented on the ALMA Board. The Board meets quarterly and has phone meetings monthly. Through their participation on the ALMA Board, NSF and AUI have early warning of issues from the other partners that could cause problems. In addition, NSF and AUI have influence through the ALMA Board on solutions to those problems. It is very important that the Board institute processes that prevent it from causing serious delays or damage the project by making no decision, when a decision is needed.

• **The ALMA Agreement** -The ALMA Agreement makes North America and Europe equal partners in ALMA. Because the cost sharing has been established based on the predetermined "value" of each scope item, each partner is responsible for covering cost increases for its scope, without passing on those increases to the other partner. This agreement, therefore, insulates the USA from needing to pay for cost overruns of the Europeans. Similarly, it insulates the Europeans from having to pay for cost overruns in ALMA-NA. However, the annual funding available to ALMA-Europe is likely be a fixed amount. Thus, cost increases could lead to schedule delays, as it takes ESO additional months to years to provide the additional funding needed to complete the scope.

• **ALMA Management**. -The close working collaboration among the ALMA partners, the numerous and frequent mechanisms of routine communication, the formal processes for managing technical changes and ensuring systems integration, and the leadership provided by the ALMA Director and JAO should help keep all parts of the ALMA project on track, minimizing the risk that problems in any part grow to adversely and significantly affect other parts.

Broadening Participation

Broadening participation in science, technology, engineering, and mathematics is a major goal of the NSF. This goal focuses on recruiting and advancing women and persons from groups traditionally underrepresented in science and engineering. Major projects, such as ALMA, which access exciting scientific frontiers and must staff up their scientific and technical workforces, have a significant opportunity and responsibility to include more women, underrepresented minorities, and persons with disabilities among their workforce and user community. These well qualified individuals often bring special talents, experience, and perspectives that add much to the effort and the field, and ALMA-NA is strongly encouraged to be proactive in this area.

1.2 ALMA Construction Cost Growth

The Panel judges the current cost estimate to be sound and solid for this stage of the project, with the caveat that the contingency appears to be too low. However, between the development and approval of the original estimate and today, ALMA has experienced a significant cost overrun. The budget approved originally for ALMA-North America by the NSF Director, National Science Board (NSB), and US Congress was $276.2 million (all costs Y2K dollars unless otherwise indicated). By contrast, the proposed new baseline requests $364.0 million from the NSF. Allowing for offsets from international partners, the project is requesting an increase of $87.8 million or 32% from NSF. Identical cost (value) increases are being absorbed by ESO. The increase would have been considerably larger (on the order of an additional $50 million for each party), except for the proposed scope reduction from 64 to 50 antennas for ALMA overall. Note that NSB and Congressional approval will be for a new baseline in "as-spent" dollars, accounting for inflation since Y2K.

There is evidence that the project personnel, management, and Board recognize that they share the blame for part of the increase, and they are taking lessons learned from this experience and using them to prevent similar surprises in the future. Some of the current key personnel have joined since the project headed off track. These individuals have been instrumental in bringing the project back on track, implementing project management systems, resolving technical issues and uncertainties, and developing the current cost estimate. As a result, the ALMA team is stronger, and one can hope that ALMA will proactively prevent and avoid cost increases and schedule delays in the future.

The project estimates this cost increase as being due complications associated with managing the project as an international partnership with no lead partner (45%), underestimation of the cost of implementation in a remote and challenging site (17%), unusually large commodity price increases (18%), underestimation of systems engineering (16%), and market conditions in Chile (4%). The original baseline cost estimate was adopted by the project in 2002, based primarily on estimates developed and prepared in 2000.

The Panel focused especially on ascertaining whether the currently proposed cost estimate and plans are likely to be adequate. Is the project organized, staffed, committed, and positioned to complete the project within the proposed new baseline? The answer to the best of our judgment is "yes."

Methodology of Original Cost Estimate

The Panel believes that a significant root cause of the cost increase that faces the project and NSF today is that the original ALMA-NA cost estimate was too low. It was developed using an older, less formal, and less robust methodology than is required by NSF today. The previous baseline included a contingency far below the figure of 35% to 50% that would be expected based on the very low maturity and completeness of the design and prototyping in 2000, when the cost estimate was first prepared. Thus, the "missing" contingency in the original baseline would come close to covering the proposed cost growth (after reducing from 64 to 50 antennas). That said, some of the cost increase has been within the control of the project and could be viewed as avoidable. Going ahead, the project team must endeavor to minimize unnecessary costs and avoidable mistakes. The experience of the ALMA management team is the best assurance that this goal can be met.

North American Antenna Contract

The total contract price is $137 million in Y2K dollars, excluding contingency, for 25 antennas. At an incremental price of $4.6 million for Antennas 26-32, a hypothetical 32-antenna purchase would amount to approximately $169 million. This compares to an original cost estimate of $91 million in the 2002 budget. After allowing for a roughly $44 million cost increase due to higher materials costs and lower antenna quantities, the remaining cost increase amounts to approximately $34 million.

The Panel was particularly interested in understanding the cost growth of the antenna contract, since it is the single largest element of the cost increase on the North American side. It grew from a $91 million ($104 including contingency) estimate for 32 antennas to a $137 million ($144 including contingency) contracted price for 25 antennas, an increase of 51%. Assuming an incremental antenna cost of about $4.6 million, the new antenna contract would have totaled $169 million if the full number of 32 antennas had been maintained, representing an even steeper 87% increase.

Only about $14 million of this cost increase was likely avoidable by the project, and the Panel believes that appropriate changes were made to prevent a similar increase in the future. As best as the Panel can tell, the antenna cost increase can be accounted for by the following root causes:

- Inaccurate cost estimate in the original 2002 budget: $34.2 million. The antennas for ALMA have extremely demanding specifications, and may well be the most advanced antennas of their size. While this represents a sharp increase in the budget, it does not represent a real cost increase that could have been avoided by the project. While manufacturing the prototype the vendor learned about these realities and their effect on cost.

- Unavoidable increases in materials cost: $13.7 million. Between the time of the initial cost estimate in March 2002 and the time the first production contract was priced by the vendor, relevant commodity prices increased by 18.4%. This represents a real cost increase, but could not have been avoided by the project.

- Quantity changes: $16.3 million. After the initial production bid was received in April 2004, it became necessary to reduce the number ordered. This proceeded in two phases: from 64 to 50 antennas with options for an additional 14, followed by splitting the contract between VertexRSI and Alcatel, which reduced volume further from 50 to 25 antennas. This volume reduction resulted in a net price increase of 12%. It was a direct consequence of the first two increases as well as the decision to split the antenna contract between NRAO and ESO. Again, this represents a real cost increase, but could also not have been avoided by the North American project.

• Insufficiently controlled antenna testing process: $14.2 million. After the initial Antenna Evaluation Group completed its tests and submitted a favorable report on the quality of the VertexRSI antenna in May 2004, the vendor was permitted to continue adjusting the prototype. As a result, the initial satisfactory tests could not be duplicated. This issue came to the attention of NSF and the ALMA Board in the fall of 2004, causing them to prudently suspend contract signing while there were still uncertainties about the surface accuracy of the prototype. This insufficient control represents a real cost increase, and would have been avoidable. Management changes were initiated and the antenna evaluation process was reorganized and completed in three and one half months. In addition, it led the ALMA Board to recognize a need for more proactive oversight, and they are changing their processes to accomplish this.

While the $34.2 million increase likely reflects inaccurate initial cost estimates by ALMA and VertexRSI as mentioned above, its sheer size may point to cost saving opportunities to be addressed jointly with VertexRSI. It also points to the need for AUI and the ALMA project to develop a better understanding of the contract's economics for VertexRSI so that they can formulate an informed management approach and potential responses to cost and schedule overruns should they occur.

Recommendations

1. The ALMA Board and ALMA-NA must develop, institute and document management and decision-making procedures that default to decisions being made in a timely manner in the interest of keeping the project moving and on track.

2. ALMA NA must increase the centrally held contingency within the proposed new baseline to a level that is in the range of 25% to 30% of the unspent and unobligated budget.

3. ALMA NA must provide strong mentoring for less experienced IPT leaders and team members.

4. ALMA NA must minimize change orders to the antenna contract, and should provide an on-site presence at Vertex/RSI plant.

5. In its staffing of the ALMA Project, NRAO should exploit the opportunity to broaden participation in the project to include more persons from groups currently underrepresented in science and engineering in the USA.

6. The ALMA NA Project should consider establishing a risk burndown approach, in which risks are assigned target dates by which they should be resolved, and progress is monitored.

7. ALMA NA must prepare monthly earned value reports, starting in March 2006.

8. ALMA should seek and expedite formal agreements with international partners who would bring valuable resources and expertise to the project. It might be useful to benchmark how this is handled in the high-energy and nuclear physics communities.

9. To establish an incentive to drive cost and schedule performance, NSF should decide if it is appropriate to encourage the Project to save contingency, by allowing them to add back antennas or implement other scope additions to improve science capability of the facility, in the event that progress proceeds on schedule and contingency remains above a pre-specified level late in the project.

10. NSF should provide clear direction to ALMA NA on the importance of the completion milestone: if it is very important to complete the Project on schedule, the ALMA NA Project Manager should ensure that the schedule has adequate float at the end of the Project.

2.0 ALMA Site Construction and Antenna Commissioning IPT

The site construction and antenna commissioning are perceived as the highest risk IPT, as measured by the Value Balanced Contingency of 17.7%, and the relatively low confidence level expressed by the IPT leads in completing the IPT on budget ($38,146K in Y2000 US dollars) compared to most other IPTs. The primary reasons for the high risk are the remote location, the high altitude, the strength of the Chilean economy, and the falling US dollar relative to the Chilean peso.

The Panel explored in some detail six major issues that impact the Site IPT. These include, the management of this IPT, the hiring of engineers and technicians for the site work, the bidding of contracts for the site work, the efficiency of the antenna construction, and impact thereon due to the two-antenna designs, the site fiber optic cables, and the power plant. The results of this exploration follow.

Management

The management of the site facilities is being carried out by the Site ITP Lead (ESO) and the Site ITP Deputy (NA). These two managers live at the Observatory Site Facility (OSF) and will continue to do so throughout the project (assembly, commissioning and operations). The Site ITP Lead and Deputy are in close communication with the ALMA Project Manager at the JAO in Santiago.

The residence of the Lead and Deputy at the OSF is vital since it provides a strong management structure for the site construction and commissioning phases, with good communication with the JAO as well as close oversight of the staff and contractors. The Panel finds that this management structure is sound and does not anticipate problems in this area.

Personnel Hiring

The quality of the hires, the methods of hiring, and the timescale for hiring were examined by the Panel.

a. Quality of new hires:

One of the most difficult challenges facing the ALMA project will be the hiring, training and retaining of the highly skilled engineering and technical staff who will be responsible for the assembly, commissioning, operation and maintenance of ALMA. There is a pool of talent in Chile that can be tapped for the engineering and technical staff in university graduates from the 6-year degree and 4-year degree programs. In order to attract the best engineers and to provide requisite training, training will be in NA or Europe, and they will participate in key aspects of antenna assembly and of testing sub-components. Some progress has already been made in hiring key staff with good experience in highly technical projects.

b. Methods of hiring

Thus far, the hiring has proceeded along the usual lines of advertising, etc. The Panel strongly recommends that, in addition to these essential approaches, a particular effort be made to attract graduating engineering students from universities in Chile, especially universities with strong electrical engineering programs, such as the University of Chile, the Catholic University and the University of Concepcion. The faculty at these universities should be enlisted to provide a first level of screening for these candidates.

c. Timescale for hiring:

The timescale for bringing in a sufficiently-trained engineering and technical staff is very short because the first antenna will be delivered in early 2007. The hiring of the necessary staff has proceeded slowly thus far due to problems related to the authority for hiring, which have now been resolved.

The Panel was pleased to hear that proposed vacancy notices for key positions will be presented to the ALMA Board on the 22nd of February, and strongly urges the ALMA management to proceed as fast as possible with hiring and training of these key engineers and technicians.

Bidding for Contracts for Site Work

The Panel was concerned that there might be "inflation" of bids for key site development tasks because of the perceived size of the ALMA project. Indeed, there have been significant increases in quotations for the same tasks since 2002.

The discussions with team members convinced the Panel that the competitive bidding process, when necessary pre-filtered to select those companies known to have the requisite technical expertise, is working well. The increases since 2002 are due to the strong Chilean economy and the demand for competing projects from large concerns, such as the mining industry, which is booming. It is clear that the experience of the JAO management and the management at the OSF in operations in Chile over the last few decades are invaluable in this regard.

Efficiency

There is some concern that the loss of efficiency due to the remote location and the high altitude of the ALMA site would cause larger efficiency losses than currently expected. In this regard, it is not possible to judge, since no project of this complexity has been carried out at this altitude before. The project has estimated that it will take, on average, a factor 2.6 times longer to commission each ALMA telescope antenna than was required for the VLA antennas. This is due to a combination of factors including the greater complexity of the ALMA antennas and the antennas systems installed at the high altitude.

Site Optical Fiber Cables

Site work at the Array Operations Site includes construction of roads and an extensive network of fiber optic cables. To minimize problems from contractor interference, the project is planning to advertise and award a single contract for this work.

The Panel concurs that contractor interference will be a significant issue for this work and that a single contract offers the best opportunity for close coordination and minimization of interference. Several members of the Panel expressed concern for the qualifications of the contractor who will undertake the installation, splicing and termination of the fiber optic cable system. The Site IPT responded that they anticipated the prime contractor for this work, most likely a civil construction firm, would employ a qualified subcontractor for the optical fiber cable installation.

To carry this out under the proposed formal prequalification, the JAO would issue a Request for Qualifications (RFQ) to interested firms, specifying the management and technical information to be submitted to demonstrate qualifications, which could include:

- Identification of the optical fiber cable subcontractor.

- Qualifications and experience of both the prime contractor and the optical fiber cable subcontractor, as they relate to the needs of the ALMA project.

- History of prior projects in which the prime and optical fiber sub have successfully worked together, including a point of contact with the owner of each project.

- Plans for qualify assurance by both the prime and the optical fiber cable sub. These management and technical qualifications would be evaluated on a ”pass-fail” basis. Only those firms that pass would receive an Invitation for Bids (IFB).

Power Plant

This is an IPT of ESO, and not, strictly, a NA concern. However, since a wrong choice at this point could have serious consequences for ALMA, the Panel did consider the possible impact of the present baseline plan, which calls for gas-powered generators, backed up by diesel generators. This was based on an assessment of the reliability of the Chilean grid in 2002, a situation that has since improved substantially, and the Panel was therefore pleased to hear that the power plant plan is being re-evaluated.
Discussion of Recommendations:

Recommendations

1. The Panel urges the Site IPT managers to proceed with hiring the needed staff as soon as possible to insure that a qualified technical staff is in place to install and commission the first antennas.

2. The Site IPT should closely monitor the progress of the commissioning and installation of the first few antennas to calibrate the projected efficiencies for antenna installation and adjust the labor requirements accordingly.

3. To mitigate the risk of inadequate technical qualification of the fiber optic subcontractor, the Panel recommends that the procurement employ formal prequalification of bidders.

4. The Panel recommends that consideration be given to requiring that the low, conforming bidder successfully demonstrate, on-site, critical capabilities, such as fiber optic cable splicing, prior to contract award.

3.0 ANTENNA IPT

Following a period of prototype antenna testing in Socorro, the ALMA project proceeded with antenna procurement and now plans to acquire antennas from two sources. ALMA NA has signed a fixed-price contract with VertexRSI for twenty-five antennas and ESO has signed a fixed-price contract with Alcatel for an additional twenty-five antennas. A contract for the two antenna transporters has also been signed. Delays in the evaluation of the prototype antennas, coupled with rising commodity prices and loss of value of the dollar compared to the Chilean peso, mean that the cost of a commissioned antenna has increased substantially since the original costing of the project. Some of these additional costs for the antennas were incurred with the re-estimation of the complexity of the antennas and the re-evaluation of the scope of work by the contractor at the OSF.

The ALMA project does not include a program of antenna testing at the high site. Information about antenna performance at the site has been provided by the APEX project, a joint MPI-Onsala-ESO project led by MPI. APEX acquired one antenna from VertexRSI. After initial problems with the hexapod were solved in mid-2005, the APEX antenna has been operated in a fairly routine manner and has produced science results. Since the APEX antenna acceptance by ESO in July 2005 and the signing of the contract between AUI and ALMA, technical information about the APEX antenna is now freely available to the ALMA project.

The decision to incorporate two different antenna designs in the array will have implications throughout the project. In this section the focus will be on just the North American antenna IPT. An analysis of the risks associated with the NA antenna contract is presented in the next section (the cost analysis was presented in the management section), while broader management issues and systems integration issues are addressed elsewhere in the report.

The Panel observed that:

1. With the signing of the fixed-price contract, the greatest risk for increased antenna cost is any antenna change orders that might be initiated by ALMA management. A secondary cost risk relates to possible miscommunications between the ALMA NA Antenna manager and the contractor, including slow response by ALMA NA to contractor queries and slow approvals.

2. The ALMA antenna test program was carried out in Socorro, but the antennas will need to perform in the harsh environment of the ALMA site. The antenna specifications are based on performance at the site, which helps to mitigate this concern.

3. The best information currently available on antenna performance at the site is from the APEX project. The mechanical designs of the APEX and ALMA NA antennas are very similar, but not identical.

4. The results of the APEX project are encouraging and consistent with the results from the ATF. Measurements of the surface accuracy indicate is it 17~microns rms, better than the specification. The blind pointing is better than the specification of two arcseconds over the entire sky, and sources are tracked to better than one arcsecond. Cooling has been adequate. Interferometric observing of course cannot be tested with one antenna. Solar observing modes also cannot be tested with the APEX antenna.

5. Communication between the APEX and ALMA project appears to be good and occurs on many levels. It is not, however, part of the ALMA management structure and relies on continued good will between the two projects.

6. The construction of the antenna erection facility and assembly and delivery of antennas are on the critical path. Delays would produce marching army cost increases.

3.1 Antenna Procurement

Because antenna procurement is the largest project expenditure (at 39% of total budget, excluding contingency), the Panel was particularly interested in understanding the details of the vendor and the contract.

Risks

While the Panel acknowledges that it could not conduct a full due diligence analysis, it nonetheless concludes that the risks of North American antenna procurement are acceptably low for a contract of this size and technical complexity.

Design Risk

While there might be small issues remaining with the antenna design, the successful antenna test program at Socorro and the successful initial operation of the APEX antenna of nearly identical design at the ALMA high altitude site gives assurance that the design is sound. The present performance of the APEX antenna at the site in terms of pointing accuracy and the surface figure of the antenna meets or exceeds the ALMA antenna specification.

Vendor Risk

Vendor risk is minimal. The North American antenna supplier, VertexRSI, is a wholly owned subsidiary of General Dynamics, a $21 billion defense contractor. VertexRSI is headquartered in Kilgore, Texas, and has revenues of approximately $70 million. It reports to SATCOM Technologies, which is in turn a division of General Dynamics' C4 (command, control, communications, computing) group. VertexRSI is the result of the consolidation of most U.S.-based antenna manufacturers over the last decade.

General Dynamics, VertexRSI's parent company, appears in strong financial and managerial condition. Its revenues have grown every year over the last 10 years at an average compound annual growth rate of 21%. During this time, net margins have ranged between 6% and 10.5%, a performance not matched by any of the other three prime U.S. defense contractors (Boeing, Lockheed Martin, and Northrop Grumman). In 2004, operating margins were 10.1%, again significantly higher than the other primes, which ranged between 4.3% and 6.7%. Cashflow was a healthy $1.8 billion, almost 10% of revenues at the time. These measures indicate that General Dynamics, the parent company, is highly unlikely to default.

General Dynamics derives 79% of its revenues from defense customers, dominated by 67% from the U.S. government. Given the likely slowdown of defense spending over the next few years, General Dynamics will likely see its organic revenue growth slow or reverse. However, its portfolio is well-diversified, covering several large Navy and Army programs, thereby mitigating revenue risk. The bulk of General Dynamics' commercial revenues comes from its Gulfstream Aerospace division, which benefits from the strong business jet market at present, and which could soften some of the financial impact or reduced defense spending.

Program Risk

Program risk is the most likely risk category for ALMA's North American antennas. However, this risk is still judged acceptable based on the following observations:

- General Dynamics has an industry reputation of very strong program management

- The ALMA contract, ranging between $20-30 million per year, will add between 30-40% to VertexRSI's revenues, and will likely be its largest program. Therefore, it will receive significant management attention from VertexRSI leadership

- Antennas of the same design have been built before successfully, including the APEX antenna and the North American ALMA prototype. There is a lingering risk that VertexRSI may find it difficult to scale up by 30-40% in a very short period of time. This underscores the need for frequent, proactive, and high-level management of the relationship and contract performance by NRAO and the North American ALMA project manager. In addition, the project should consider examining the cost and schedule performance of VertexRSI's past large contracts to further assess the likelihood of slip and develop an appropriate management plan.

Contract Risk

It appears that the contract of AUIwith VertexRSI contains no undue risks. Strengths of the contract include:

- Indexing of the purchase price to price indices published by the Bureau of Labor Statistics, allowing ALMA to benefit from potential commodity price declines. A price ceiling, used in the budget, limits price escalation risk.

- Technical specifications include performance on site. This ensures that VertexRSI bears the responsibility of ensuring that the antennas work as expected in the difficult conditions of the ALMA site.

- VertexRSI warrants the performance of each antenna for 24 months after delivery or 18 months after acceptance. As long as the ALMA project tests antennas immediately upon delivery to the OSF and the site, this period provides ample time to recognize and address any problems.

- 10% of payments can be withheld by AUI until acceptance of each antenna. This ameliorates the lack of performance incentives in the contract, one of its key deficiencies. The 10% effectively make this contract similar to a an award fee contract, which is occasionally used for prime defense contracts, and which is effective at ensuring vendor performance.

- Change orders must be confirmed by VertexRSI in writing within 30 days. This helps ensure that VertexRSI will not misinterpret casual conversations as change orders without the project's knowledge.

• Key personnel are named in the contract, covering the project director, the head of the European project office, and the OSF site manager. This provision ensures that VertexRSI will not switch to the "C-team" once the contract is signed.

• AUI is only committed to purchasing the antennas covered in the current funding allocation, with no guarantee given to purchase all 25 antennas. This could potentially allow the ALMA project to switch to the European antenna vendor should significant performance lapses occur.

Recommendations

1. Continue communication between the APEX and ALMA projects to identify possible antenna performance issues at an early stage.

2. Closely monitor the antenna delivery and acceptance timeline and provide experienced contract management support particularly in the area of the control of change orders and communication with the vendor to avoid delays and cost increases.

3. Pay close attention to the maintenance of the transporter and to the training of transporter operators.

4.0 Front End Electronics IPT

The Panel did not look at the front end electronics in detail. From the presentations there are a few observations that may be useful in following the progress of the front end electronics construction and installation.

The principle risk is not technical but labor related. NRAO has committed to build only band 6 receiver inserts that are not the highest frequency, but they are still very demanding parts to assemble, even in small numbers. It is as much an art as a science to build these receivers. Assuming that about half of the SIS mixers meet spec, and that there are 3 spares, then about 210 mixers must be assembled and tested. This is a probably a number comparable to the total number built to date in the world, and they are the most complex ever built. NRAO has several long term employees in this area and they are extraordinarily skilled at this work, but the staff is fairly small, and there is an stated need to bring in new people. The skills required to do this work are not easily acquired, and typically one to two years of training are needed on the job to be most effective. In the process, some people discover that they can never do this work, and only a few become exceptionally good. It is an open question how long these people can last in a production environment, and whether the present success rate can be equaled with new personnel. It may not be correct to extrapolate the present production rate into the future. Rather, production could possibly slow down, and costs rise with time.
The construction of the LO system for bands 3, 6, 7, and 9 receiver inserts is entirely the job of NRAO, and while the work is less complex than the mixers for the Front End electronics, there are many parts to test, and many possible interactions. Skilled people

are needed for the assembly and testing work, although most of the multipliers have been obtained from an outside vendor.

Present performance of the 2nd LO synthesizer and 1st LO offset generator do not currently meet requirements. These are difficult parts to debug and the problem may lie in the embedded software. The formatter for the fiber link also has problems perhaps related to firmware. Risk of failure in either case seems very low, and the cost impact appears minor.

The Band 9 LO does not yet meet the required power over the band, and the solution may not be simple. Technically this is a very difficult system to build, and it is on the edge of (or slightly beyond) the state of the art. For this type of development, contingency must be very high since there is no way to anticipate all difficulties.

5.0 Back End Electronics IPT

Back End Electronics

Almost all of the Back End electronics components are fairly conventional with the exception of the laser local oscillator (LO). Most of the assemblies are outsourced, and present little risk. The sheer number of parts presents inventory problems. Almost all systems have been completed as prototypes, and meet requirements. However, even with excellent system engineering there are likely to be problems with the overall integration of assemblies. Amplitude flatness across the IF band is one concern, and this affects overall system noise. Even with no risk in the production of parts there is still a significant integration risk due to the complex interactions between parts. It should be possible to fully resolve this before production quantities are built, as long as all hardware is available, but in a distributed effort such as this, such an all-up test may occur relatively late.

The Back End Electronics IPT has a complex mix of electronic deliverables within ALMA. It breaks down to 22 discrete electronic modules contained primarily within the analog, digital and central Local Oscillator (LO) racks which are housed in the Antenna Operations Site (AOS) at 5000 meters. In addition, the Back End IPT will deliver modules to the Correlator and Front End IPT's. In total, 1281 electronic modules must be procured, assembled, tested, delivered and integrated.

The current status is that 17 of the 22 required electronic modules have working prototypes. These have been delivered to System Integration for testing.

Observations made during the breakout session:

1. The Back End technical requirements are approximately 50% verified. There are remaining Final System Technical requirements that have not yet been delivered to the Back End IPT.

2. The supply chain for the backend modules is very complex spread among ALMA partners and industry. There is also a wide geographic spread of suppliers. The logistics associated with this arrangement will be difficult.

3. The staff on hand during the breakout came across as very straightforward, confident and technically competent. They gave informed responses to our questions.

4. A complete end to end system test of Back End modules is yet to be performed.

5. The Product Assurance activities planned are sufficient to deliver quality products.

6. System Engineering principles are being used though there could be more rigor in this area.

7. The Cost Estimate Information sheet for the 2nd LO Synthesizer (LO2 WE 3830) was examined for completeness. The methodology used to fill it out was adequate and the basis of estimate improved from the original baseline.

8. The Back End IPT feels that the ALMA management structure in place fully supports decision making at the IPT to IPT level.

9. There is adequate shipping time in the schedule for the delivery of products from North America to Chile.

10. If at some point, ALMA grows to greater than a 50 antenna array, the Back End IPT will be able to respond with additional hardware in a straightforward manner.

11. The deliverables of the Back End IPT lend itself well to the development of performance metrics that are easy to track and to understand.

12. $26 million of the outstanding $36 million Back End Electronics budget remain an engineering estimate. The engineering estimate is well understood mostly based on actual quotes and proposals from various suppliers.

13. It is understood by the Back End IPT that supplier management is essential to the success of delivering modules on time and on budget.

14. All custom integrated circuits required for the Back End are on-hand.

15. All items of importance will be serialized and tracked in some, as yet to be determined manner.

16. There is an area for segregation of non-conforming materials in Socorro, the main Back End integration site.

17. All professional staffing for the Back End IPT is in place. There are no outstanding key hires to be made.

18. The Back End IPT Risk Register was shown to be an important tool to understand and mitigate risk.

Laser Local Oscillator Reference

There has been significant progress recently on the local oscillator reference (LO), and it now appears that the phase noise specification from the synthesizer can be met with the components on hand. Present phase noise measurements show that the majority of noise comes from the reference oscillator, which can readily be improved. This eliminates the need for a parallel effort on the reference. Reliability still needs to be improved, but this seems straightforward, and is related only to a few modules within the synthesizer. Reliability affects costs since laser spares would be needed. There are two complete laser synthesizers within the complete system. There is a concern that the master laser is available from only a single source, and exceeds any industry requirements. Thus there is little recourse should this company fail to deliver.

Another concern is the phase drift within the long fiber runs, and particularly within the cable wrap, due to fiber dispersion and depolarization. The relative magnitude of these problems may not be assessed until on-site testing, where work is difficult. However, any problems should be serious only at the higher frequencies, and will not need to be solved immediately. In the worst case, the fiber cable wraps within each telescope might need to be replaced, but this is not a very difficult process. The cost risk seems mostly to be from a significant amount of on-site labor needed to debug the phase problems, and the accompanying schedule slip.

Back End Electronics Costs

The Panel investigated the cost estimating process in the Back End electronics area to validate, by example, cost estimates of similar parts of ALMA. It also attempted to understand its level of development since this defines the 'to go' risks. Costs for the Back End electronics appear to have been estimated by a 'roll-up' of parts and labor estimates with contingency or reserve added. The Back End electronics will contain at least 22 different module types to be replicated into at least 1200 electronics boxes or sub-assemblies. There are some one-of-a-kind items. All but a few of these different designs have been prototyped and exist either in pre-production prototype or in high fidelity bass board form. The bulk of the future effort will be a manufacturing, integration and test task and except for some units at pre-PDR development and units in the photonic LO system, at the point where manufacturing can begin. This means that perhaps 90% of the parts have been identified and ordered in appropriate quantities, board layouts and designs finalized, firmware written and most assembly and test processes defined. Furthermore, almost all of the manufacturing is truly concurrent and much of it will be performed out-of-house. In this case, where both component and labor costs competently estimated, the cost roll-up should be accurate. If this were for example a NASA project, appropriate management reserves for vendor supplied parts or within state-of-the-art new designs at or beyond CDR would be 10-25% of the ‘to go’ costs. Good management practice would release almost all of the reserve to the IPT to facilitate efficient manufacturing of the large number of boxes,

The Panel briefly investigated the quality assurance and reliability approach for this IPT. It appears to conform to standards and practices in large-scale scientific programs.

A number of comments that relate to the Back End electronics are listed below:

1. At a higher system level, it is important for the Final System Requirements to be finalized. The delay of establishing requirements may lead to unexpected consequences the further one progresses down the path of design to production. This risk has been picked up in the Risk Register but it would be good to establish a firm date for the delivery of Final System Requirements to the various IPTs so subsystem design and verification can continue with the confidence nothing major will change in the future.

2. The supplier matrix and mix of Back End deliverables will be a challenge for the Back End IPT to manage. While there was an impressive display of technical talent in the breakout session, the mundane element of logistics may be under appreciated. ALMA may want to consider partnering with a freight management supplier/forwarder that has offices in North America, Europe and South America. Tracking all of the cargo using Excel spreadsheets will be difficult. It was hard to determine how the actual logistics costs were broken out between the Logistics WBS element and logistics within the IPTs.

3. While reviewing the Cost Estimate Information for the 2nd LO Synthesizer, there are two items that could use additional review and/or information: 1. The technical risk and the cost risk factors were both set to one, the highest confidence possible. Given that the BE system has not gone through end to end testing nor have the final requirements been set, it is interesting that the confidence level can be one. 2. The amount of labor associated with testing and failure analysis has the potential to be set too low. There must be some assumption that the yield on the electronic modules will be very high.

4. The suppliers must be very actively managed. The Panel suggests that the Back End team explicitly identify their top 5 to 10 suppliers and create a system by which the performance of the supplier base can be assessed on a regular basis.

5. The performance metrics for the Back End IPT in the end needs to be directly linked to the shipping performance relative to delivering 1281 modules on time and on cost to Chile. This can be tracked using simple Excel charts that show planned versus actual shipments. This can augment the Earned Value System with an easy common sense check.

6. While there is a commitment to the tracking of the serial numbers of the individual configuration items, the system by which this will be done is yet to be defined. Again, simple Excel spreadsheets might not do the job for a system with as many components as ALMA.

7. The strategic decision to decentralize System Engineering to the individual IPTs will work only if the team members have adequate training and there is a management commitment for rigorous System Engineering to take place. It would make sense to make up a simple chart that shows the 22 individual Back End configuration items and the progress against the System Engineering plan of PDRs, CDRs and PRRs. It would be a good thing for example to point to a single Production Readiness Review that addresses the Back End IPT deliverables.

8. While the list of Product Assurance activities is impressive, the actual evidence of their use and implementation is not strong at this time. This is a consequence of the maturity of the design. As time marches on however, items like log sheets, travelers, test plans, packaging instructions, and procedures will increase in importance. This area will continue to require a high level of management attention.

Recommendations

1. The suppliers must be very actively managed. The Panel suggests that the Back End team explicitly identify their top 5 to 10 suppliers and create a system by which the performance of the supplier base can be assessed on a regular basis.

2. Develop an effective management scheme for assuring that all the needed components for the Back End electronics arrive on site when needed. Consider partnering with a freight management firm with offices in all three regions.

3. Work with management to make sure that good system engineering practices are carried out in the other IPT's to avoid adversely affecting the Back End IPT.

6.0 Correlator IPT

Although the Panel did not look at the Correlator IPT in detail the following observations are appropriate based on the presentations. The correlator is a separate IPT but it resembles the Back End electronics in many respects. The total task is more than 70% complete and actual manufacturing is about 25% complete. This is the only IPT where EVMS data have been collected and can be examined. Performance indices relative to the 2002 baseline are good although some of the tasks completed were level-of-effort. Performance indices in the WBS elements for the manufacturing of the 1st and 2nd correlator quadrants were apparently low (composite indices around .8) although it's not yet clear whether this performance indicates real cost or schedule issues. The data appear to be sufficiently complete to compute individual cost performance and schedule performance based estimates at completion (EAC). The Panel notes that EAC based on cumulative CPI, and SPI are historically indicative of the floor and ceiling of the real cost at completion and should be tracked in all IPTs. See for example, Christiansen, D.S., "Using performance indices to evaluate the estimate at completion", J. Cost Analysis, 17, 24, 1994. Although it would be a non-standard application of EVMS, the correlator performance might be used to estimate the uncertainties in other ALMA elements that involve manufacturing such as the back end electronics (and front ends).

The Panel notes that nearly all the components for the correlator have been ordered and one quarter of this key element has been operational for nearly one year. The rebaselined cost of this IPT is less than the original budget estimate and is on track.

7.0 Computing IPT

The mission of the Computing IPT (CIPT) is broad and quite diverse covering the computing needs for the science pipeline, and the software for monitoring, controlling and commissioning a large number of devices.

The CIPT has done an impressive amount of work in defining the scope of work and making a detailed plan of the tasks that must be carried out based on the scientific and technical requirements. The CIPT is an area where Japanese contributions are completely integrated into the plan and presumably "counted on" to carry out the work, even if not formally committed or included in the cost estimate. The CIPT leaders don't seem to consider this as a risk.

The majority of the high level work elements of the CIPT's WBS are shared between North America and Europe. Less sharing of WBS elements would have been preferable from a management perspective, but that appears to have been politically impossible. That said, there appears to be good cooperation and communication between the two groups. The organizational structure used to manage and carry out the work has a very large number of boxes, each with a rather small number of people. The boxes are closely aligned with the areas of work. This places most of the responsibility for tracking the work on the CIPT leaders.

The CIPT has developed a very impressive system for tracking and estimating Earned Value by using a system of "Releases" each with designated "Features" of small enough size and duration to provide for estimation and tracking. This indicates a strong and clear thinking management for the CIPT on the NA side. Their plans are excellent and they have a well articulated approach to computing. In addition their tracking system is excellent and they have good communication mechanisms with many well documented meetings.

They have a great approach for bringing scientists into the requirements and testing process – to assure that the software and systems meet the needs and perform as required. This is a classic problem area for IT projects – getting the attention of the scientists at the right time. This area may need continued higher level management attention and support.

ALMA computing is a multi-institutional, multi-national effort that does add some complexity, but appears to be functioning well with many good communication mechanisms.

CIPT (NA) appears to be very competently run and stably staffed by good people, but it is a lean organization. A small fraction of the total project resources are being put into the computing area seemingly to achieve the minimum necessary. This leaves little room for providing solutions that might considerably improve the efficiency of monitoring, operations or access to data in ways that cannot be known or foreseen three years in advance.

The software releases are linked to hardware events rather than to specific dates. This is a sensible approach. However, he Panel had several concerns related to ALMA computing:

- The risks related to the large number of Interface Control Documents and the potential for late changes may not be adequately represented by "DOE method", even with the highest risk category and weight.

- The risks related to the blurring of construction and operations activities, which will inevitably occur during commissioning and early science may not be adequately represented by DOE method. They are characterized by the "Conflict of Priority" risk.

- The risk related to small granularity in the division of tasks - i.e., software blocs are divided among groups rather than being assigned to one co-located group.

- There is no specific work element defined for provision of IT help/solutions that are not yet identified but which might have great potential to advance the project. These will emerge despite all the attempts to plan in advance.

- The large number of small boxes in an org structure puts a lot of pressure on the CIPT management.

- The funding profile looks rather flat and might benefit from front-loading the labor effort to get a fast start and stay on schedule (adding people to a late software project doesn't help).

- It is not clear that the CIPT management will recognize slippages and increases in the scope of work expected from computing early enough to react, other than by changing priorities and moving staff between tasks.

- The risks related to the establishment of a computing organization in Chile (to serve as the front line for operations and problem resolution) are billed as soon to be retired.

However finding this staff and getting them trained may be harder and more time-intensive for the current team than anticipated – and it should have started already

• The ramp-down of Computing FTEs in 2009 is based on assumptions about the operations budget picking up salaries of many of the staff and picking up additional “Feature” development and new scope. Since the full scope of operations is not understood and the type of staff needed in this period not fully analyzed, this is a risk to the ability of Computing + Operations/Computing together to deliver what ALMA needs. The CIPT may need help in getting the attention of the scientists and customers of the software to validate the software and provide structured feedback.

Recommendations

1. Consider adding necessary features to the software releases earlier and “finish” the basic functionality required earlier, thus more effectively mitigating some of the large risks associated with so many different interfaces, potential increased scope and conflicting priorities during commissioning.

2. Make sure that the handoff between the construction project and operations is properly understood and documented and that the need for ongoing future development of the software is properly included in operations. Software development will continue throughout the operational life of ALMA as it does for all other major scientific facilities.

3. Because of continuing need to modify/upgrade/optimize the software during the operations, the computer group should remain at about the same size as it is during construction.

4. Consider grouping some of the boxes in the CIPT organization to reduce the load on the CIPT management.

5. Management should persuade scientists to test and provide early feedback on the effectiveness and reliability of the developed software packages.

6. Proceed aggressively to get the computing support in Chile hired, trained and integrated.

7. Be proactive in staying abreast of the progress and requirements and take corrective action early if the variances are growing.

8.0 System Engineering and Integration IPT

System Engineering Management

ALMA Systems Engineering has been divided into four main areas:

1. General Systems Engineering (SE) which covers the more classical areas of SE including documentation management and control, requirements and specifications, configuration and interface control, performance budgets and end to end system modeling.

2. Product Assurance (PA) which establishes and manages the product assurance activities of the entire project and oversees the PA activities of the individual IPTs.

3. Prototype System Integration (PSI) which utilizes the Antennas Test Facility (ATF) to integrate and validate the ALMA electronics and software systems.

4. Assembly, Integration and Verification (AIV) which plans and executes the final assembly and integration of the major sub-systems into a working antenna and interferometer systems, verifying the performance and delivering the complete system ready for science.

These four elements of ALMA systems engineering are divided into separate units under the combined responsibility of the executive agencies and the Joint ALMA Office (JAO) through the position of Project Engineer. This systems engineering structure has evolving over the past several years and management of system engineering within this structure is more difficult because of unclear lines of responsibility and authority. Systems engineering is a project activity which benefits from a clear project-wide organizational structure. During the review the Panel heard several times of occasions where this lack of structure has caused additional problems, for example configuration control during antenna prototype testing.

In this phase of the ALMA project, with the potential for cost-growth due to technical scope creep, it is particularly important to develop a strong systems engineering management structure. For example to develop and maintain the sub-systems requirements documents and ensure changes are made through the project wide change control process (CCB).

Strong links need to be developed and maintained between the system engineering activity and the upper ALMA management to make best use of the analysis and control activities of systems engineering for project management and oversight. One example of this is the timeliness of approval of the essential system engineering planning such as the AIV staffing plan that is now ready for project approval.

General Systems Engineering

The general systems engineering area covers such activities as: documentation management and control; configuration control; requirements and specifications; and system performance modeling. In any large project a typical rule-of-thumb is that ~10% of the project activity should be devoted to this type of general systems engineering. In ALMA, where there is a duplication of large numbers of identical sub-systems made by a large number of internationally dispersed organizations, this is even more important.

Due to the structuring of the systems engineering IPT and the division of effort between the executives, this general systems engineering activity has been concentrated more on the European side of the project, with less opportunity for direct North American involvement in managing and prioritizing the activities. Clearly this essential work needs to be applied uniformly project wide, therefore it is important that responsibility and authority for general systems engineering must come clearly from the JAO via the Project Engineer as the responsible person for project-wide systems engineering.

The activity of document management and approval has been done until recently by European system engineering due to a lack of resources on the North American side. However recently, this work has been handed back to the JAO and is under the responsibility of the ALMA Project Engineer. The ALMA documentation archive is used extensively by all parts of the ALMA project and will become a valuable resource as the project moves towards the final stages.

The development and finalization of the project requirements and interface control documents (ICDs) are well advanced. The top-level requirements and major ICDs are completed and are approved and under configuration control. Some of the sub-system level requirements and ICDs are still under development. Currently the requirements documentation is 72% complete and ICDs 70% complete. A preliminary requirements review was held in July 2005 and a final system requirements review is planned for March 2006. Completion and approval of the requirements documentation will be an important step to freeze the technical design of the project and minimize scope creep induced cost increases.

Configuration controls are well-advanced with a comprehensive change request procedure being used by all levels of the project. Project management uses change control as an effective tool in defining and regulating the project budgets. The Change Control Board meets regularly and processes typically 4-5 major change requests per month, with a larger number of IPT level changes being controlled and documented.

System models have been developed which allow some level of end to end assessment of technical performance. An ALMA simulator has been built using a spreadsheet parametric model, and it is planned to develop this further using a more robust software tool for monitoring the effects of sub-system technical trades on overall system performance. The Science IPT provides additional assistance with detailed system performance calculations, for example assessing the effects of the two antenna types on overall interferometer performance. Additional system modeling is also planned to assist particular aspects project work such as an antenna optical model. Other system engineering activities include: space allocation management, for example in the antenna electronics racks; design standards especially in critical areas like electro magnetic interference minimization.

Quality Assurance (QA)

The assembly and integration of ALMA involves the procurement and installation of a large number of components and major sub-systems from a variety of suppliers over an extended delivery period. Ensuring high quality and operational reliability will require a thorough and well-managed quality assurance process. Systems engineering has been responsible for developing project wide standards and procedures for quality assurance and overall management of these processes. However, the main activity in quality assurance at the IPT level is the responsibility of dedicated QA staff within each IPT.

The recruitment of the important position of the QA manager is currently underway. It is hoped to find a senior person with extensive industrial experience in this field. The QA activity associated with the antenna procurement is an important part of the project since they are each a large budget item and must have demanding requirements of performance and reliability to ensure the success of ALMA. The front end, back end and correlator manufacture are also critical procurement activities that would benefit from a good QA program. In-house manufacture of some of these components is both a challenge and an advantage for QA. There was considerable evidence during the visits to the NRAO labs involved in ALMA development that an effective QA approach was already in place.

Prototype System Integration

The Prototype System Integration (PSI) uses the two antenna prototypes at the Antenna Test Facility in Socorro to system test and verify the advanced prototypes or preproduction sub-system units of the front end, back end and correlator electronics hardware and software. The units themselves are expected to have had documented testing and verification individually prior to integration into the prototype system. The PSI will also be used as a test bed to develop the procedures and verification tests which will later be used for the AIV of the production units in Chile. The operational and maintenance requirements can also be developed using these prototypes.

In order for this activity to be successful there will need to be tight control on the configuration and tracking of changes and modifications to the hardware. Good communication and documented feedback to the IPT teams on hardware modifications and debugging will provide considerable advantages in minimizing the need for a more difficult continuation of this work in Chile. However, in order to be successful strict control and documentation will be needed. This is where the strong leadership of the systems engineering group will be important.

The PSI group has recently been considerably strengthened by the recruitment of Peter Napier, an NRAO Socorro engineer with many years of experience with the VLA and large project management. In addition, the PSI group has a strong technical representation from experienced VLA-based engineers and technicians who will be a valuable asset to the system debugging and AIV development.

Prior to the installation and integration on the prototype antennas it is planned to demonstrate a full electronics end to end system test in the lab at Socorro. This is planned to start in February 2006. The PSI integration on the antennas is planned to start in April 2006, with the first production units being available by end 2006. Work on the PSI facility will continue through 2007, at which time it will be closed down and the hardware moved to Chile.

Assembly, Integration and Verification

The Assembly, Integration and Verification (AIV) of the ALMA antenna system represents one of the most significant challenges of the project. The sophisticated sub-systems, technically demanding performance requirements, the remote site and the extended delivery schedule of the fifty antennas, all combine to make this a challenging task. The Systems Engineering IPT is in the early planning stages of the assembly, integration and verification, but it will later become one of the most dominant activities of the IPT.

The work is planned in two phases. Phase 1 AIV will be to assemble and integrate the first six antennas as well as the interferometer and site infrastructure. During this period, the remaining technical problems not uncovered during the PSI activity will be need to be solved, and a more precise set of procedures, methods and tests developed for handling the production line of antenna AIV which will occur over subsequent years. The first antenna is planned to arrive in October 2007.

Some additional tests on these first antennas will be needed once they are delivered and installed at the high site. Since the antenna acceptance will be done at the OSF, any discrepancies that show up during these tests will need to be dealt with under the warranty provisions (12 months plus addition 6 months if the antenna is not used for operations). Note that it will be particularly important to ensure that this warranty period is fully exploited and all possible tests to uncover problems are planned and performed.

Phase 2 will consist of the serial assembly of the remaining 44 antennas that are delivered and handed over to the antenna AIV teams at an initial rate of one per month, followed by an increase to two antennas per month as the delayed European antenna delivery starts up. In order to handle this production rate, a large AIV staff should be ready with well-understood tasks and documented procedures (which were developed during Phase 1). In addition, there will need to be sufficient work areas and warehousing and supply chain management for the hardware to be installed.

To staff up for this level of activity will require a major recruitment effort and a carefully planned program of training and skill development. It is planned that the majority of these staff will be recruited in Chile, with some core expertise provided by international hires (13 out of total staff of 72), probably on temporary transfers from other IPTs and the home-base ALMA organizations. This has been factored into the staffing plan for these IPTs. In particular starting in mid-2007, it is planned to seed the initial AIV teams with PSI staff who will have considerable integration experience due to their work with the prototype system.

The extra recruitment effort requires additional human resource support and this has been included the rebaselined costs with an additional 8% of staff budget being provided for recruitment. Attracting this large number of highly qualified Chilean staff is going to be challenging. The recruitment effort has been initiated by approaching the major Chilean university engineering schools. It was suggested by management that promoting the best Chilean staff to senior positions as soon as possible would assist with the recruitment of new staff and provide a good structure for a largely Chilean-based staff.

To estimate the requirements for the AIV staffing as well as the site infrastructure required to support this activity, a detailed schedule (600 element) has been drawn up for the Phase 1 AIV work. This provides detail at a daily planning level and is resource loaded to assist in the planning for optimum use of staff. This planning shows a total of 354 person-days will be required to complete AIV on each ALMA antenna. For comparison, the same activity for the VLA antennas was estimated as 150 person-days. The differences were attributed to the more exacting requirements of the ALMA antennas and the more difficult working conditions of the remote Chilean site.

While the present detailed AIV schedule is sufficient to provide a reliable estimate for staffing and budgetary aspects for planning, it lacks sufficient real-world experience to provide a very precise estimate. It is probably only precise at the 20-30% confidence level and is more likely to be a pessimistic overestimate. It was suggested that some "day-in-the-life" type scenarios might help refine the detailed schedule and highlight ways in which problems might be overcome and inefficiencies prevented. For example, the effect of the 8 days on - 6 days off "turno" working scheme might have considerable impact on the work patterns best suited to antenna integration. It might be better to think about an additional AIV integration line to allow a single AIV team to "own" an antenna from start to delivery. The first phase of AIV will help considerably to better refine the processes and requirements moving from the more demanding production line activity.

The effect of the two antenna types and the delayed delivery schedule for the European antennas was taken into account during the rebaselining. During Phase 1 it was estimated to cost an additional $1.5M due to the extra complexity of having to integrate two different antennas. The late antenna delivery and the peak AIV output of 2 antennas/month adds an additional 3.5 months to the overall project schedule.

The maximum delivery rate for AIV is determined by an upper limit for the size of the AIV staffing that is set at a peak of 72 people. The ramp up and down for peak rate AIV will challenge the ability to recruit new staff, followed during ramp down by the need to lay-off staff and the subsequent staff morale problem. This might be handled by providing an extra bonus for short-term fixed term staff or by extending the period of final antenna delivery. The use of contractors for some aspects of the AIV work should be investigated as this would allow a flexible approach to the staffing requirements during the peak workload and free up the key ALMA staff for the more critical activities.

Once the first group of antennas is delivered for commissioning and science operations, the AIV staff will provide some on-going technical assistance. It is planned to transition the AIV staff gradually into operations support in a way that retains some core expertise and technical continuity, as well as an on-going career path for staff recruited for AIV.

The AIV activity has a budgeted contingency of ~10% ($3M) which is essentially the salaries of the AIV team. This appears low, considering the importance of this essential project activity. It was discussed with the ALMA project management suggesting that they hold some of the overall project contingency of $20M as a back-up contingency for AIV. There is also some built-in contingency within the budget estimates. The detailed AIV plan is rather conservative and the estimates may be reduced as experience is gained during the first AIV activities. In addition, there are seven extra staff positions included in the budget as contingency for staff leave, etc, above that required by the detailed AIV schedule. In the schedule, there are a number of periods of "float time" where some activities must wait for others to finish which is also another form of contingency.

System Engineering and Operations

The staged delivery of the antennas and the ramp up for initial science operations overlapping with the AIV activities represents a unique opportunity to obtain the maximum benefits from these parallel activities. Because of the limitations of North America's construction and operations funding, it is necessary to provide a strict division between these two areas of work. However, the AIV activities are a natural lead-in to operations and staff engaged in both sides can benefit. AIV staff will be key to training and transfer of expertise and experience to the operations staff. Operations staff can provide valuable feedback and real-world experience back to the AIV teams. To best manage this combined activity and ensure a smooth transition from construction to operations, management should consider transferring AIV to the ALMA Head of Technical Engineering.

Many of the operational tools and procedures for operational support can be established before AIV starts. These should include: fault reporting and follow-up; an integrated computerized maintenance program and work planning software; engineering data monitoring, archiving and trending software; an electronic documentation and drawing archive; and remote technical support facilities such as portable video conferencing and remote computer control login capabilities.

System Engineering Issues

• System Engineering (SE) is an important part of the ALMA project because of the duplication of large numbers of identical sub-systems and the international multi-organizational spread of the project. Many aspects of ALMA SE are well-organized and running successfully, however some activities are delayed and are in early development, which limits their effectiveness to support the project.

• JAO and the project engineer need to take charge of system engineering as an ongoing functioning tool. System engineering of the overall system may provide opportunities for cost savings, increased reliability, and reducing risk by trading performance specifications among system components and still achieve overall system performance.

• Assembly, Integration and Verification (AIV) which currently falls under the SE responsibility is a very critical step in the ALMA project. Preliminary planning of AIV has been done with a detailed schedule and staffing and resource estimates that have been used to derive a budget and the infrastructure requirements. These appear adequate to complete the project. The proposed two-phased plan for AIV will allow refinement of the process and further development of the optimum cost-effective approach as the project evolves.

• The staged operational startup and the overlap between construction and operations, the relationship between AIV and technical operations is an important consideration. This area could benefit from investigation of alternative approaches. Moving AIV to become the responsibility of observatory operations at a very early stage should be considered while retaining a mechanism for clear separation of funding.

Recommendations

1. The JAO and the project engineer need to take charge of system engineering as soon as possible and use it as an ongoing functioning tool. System engineering of the overall system may provide opportunities for cost savings, increased reliability, and reducing risk by trading performance specifications among system components and still achieve overall system performance.

2. Continue to develop a plan for a smooth transition from the construction project to early operations to retain as much of the expertise gained during construction in the operations staff. This plan must satisfy the MRE constraints separating construction from operations.

3. The assembly of hardware at the high observatory site is recognized as a challenge. Every effort should be made to have this be made as simple and as straightforward as possible. Safety in this environment must receive the highest priority.

9.0 Science IPT

The Science IPT provides the simulation support and defines specifications for the needed software for converting the signals from the ALMA antennas into observational results. This IPT also will interact strongly with the AIV process to verify that the antenna array is performing to specification as an interferometer.

The team will have the opportunity to produce the early science from ALMA which after the installation and commissioning of the first few antennas will be the most sensitive millimeter array in the world. This is both a strong attraction for the best scientists and a management challenge to carefully observe the sharp boundary between the MRE construction project and early observatory operations.

The setting up of the two ALMA data analysis centers, one at NRAO for North America and one at ESO for Europe appears to be going well. While the Panel did not look into this component of the project in detail, the concept, the planning and the initial implementation are sound.

Appendix A

ALMA NA (North America) Cost/Management Review Charge

Overall Process: The ALMA North America Cost/Management Review (NACMR) will follow, but be independent of, the ALMA Delta Cost Review (ADCR): The ADCR will report to the ALMA Board and will utilize the personnel of the original cost review panel. The NACMR will report to NSF, and will consist of a separate group of reviewers.

Goals: The main goals of the NACMR are to:

- validate the cost, schedule and funding profile for North America's share of ALMA construction;

- validate the ALMA operational concept and cost;

- validate the ability of AUI/NRAO to complete the construction of ALMA successfully for NA, based on its heritage and ownership of the ALMA concept, and performance in ALMA to this point;

- review ALMA's construction cost growth and confirm that these costs are now fully understood and contained.

The NACMR panel will be appointed by NSF. The panel will address its charge using the material provided for the original and subsequent delta ALMA cost reviews, the reports of those reviews, in addition to material specifically provided by the North American ALMA project.

Presentations for the NACMR will be led by the North American ALMA Project Manager and will be supported by NRAO staff and AUI management.

The additional material provided by NRAO for the NACMR (due the week of 23 January) will include:

- the presentation materials and the panel report from the Garmisch rebaseline cost review;
- the latest version of ALMA project brochure;
- a management plan describing the North American project's interface to the rest of ALMA;
- a detailed construction schedule;
- a detailed work breakdown structure for NA efforts in the project;
- a revised cost to complete ALMA construction for the North American part of the project together with the necessary annual expenditure levels; and
- an analysis of North American risk and contingency.

Detailed Charge: Utilizing the review presentations, the report of the ALMA Cost Review, the preliminary report of the ALMA Delta Cost Review panel, and the written material provided in advance by NRAO, the NACMR panel is asked to:

1. drill down into selected Level 1 areas of the ALMA WBS to confirm the completeness of the full project WBS at a detailed level and the adequacy of proposed mechanisms for quality control and assurance;
2. look at the schedule and consider risk implications and effects on contingency;
3. understand the cost increment associated with the hybrid array;
4. validate the proposed North American costs, schedule, and funding profile;
5. assess the adequacy of contingency for the North American part of ALMA;
6. comment on the sensitivity of the NSF-funded share of ALMA to factors outside the North American part of the project;
7. evaluate whether AUI Management of NRAO/ALMA is
    a. dedicating adequate resources to the oversight and management of the project;
    b. optimally configured for oversight of NRAO and NRAO management of ALMA tasks;
    c. staffing key project management positions in a timely manner and with effective people;

    and to recommend what charges – if any – should be made to AUI's management structure and practices to help assure the ultimate success of the ALMA project on both the regional and international levels.

Logistics and Follow-up

Location of panel review: Charlottesville, VA (inclement weather backup will be NSF)
Date: January 30 – February 1, 2006.
Duration: 3 days
Deliverables: Panel report due no later that February 17, 2006.
Follow-up: NSF Director's review of ALMA March 2, 2006
NSB Action: Meeting of May 9-10, 2006,
Schedule Milestones:

- NSF Director's Decision; Not later than **10 March**
- Draft Board Package Due to MPS: TBD (extension beyond February deadline will be needed)
- DRB: TBD (may need special DRB session)
- NSB Mailout: **April 11**
- NSB Meeting: **May 9-10**

Appendix B

Membership of NSF ALMA NA Cost/Management Review Panel

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Appendix C

Agenda
ALMA NA Cost/Management Review
Charlottesville, VA
January 30 – February 1, 2006

Monday, January 30

8:30	**Executive Session: Welcome and Charge**		
9:00	Welcome and Introductions		R. Dickman
9:15	Overview: The International ALMA Project		A. Russell
9:35	Radio astronomy/interferometry tutorial		F. Lo
9:45	Science Requirements		A. Wootten
10:15		Coffee Break	
10:30	Flow-Down Technical Requirements for ALMA		D. Sramek
11:00	**Project Overview – Part I**		
	11:00	Rebaselining Methodology	A. Russell
	11:30	New baseline plan: Cost Risk & Contingency	A. Russell
12:45	Executive Session (optional)		
13:00		Working Lunch	
13:30	**Project Overview – Part II**		
	13:30	Management IPT	A. Russell
	14:00	Site Development IPT	E. Donoso
	14:30	Antenna IPT	J. Zivick
	15:00	Front End IPT	J. Webber
	15:30	Back End IPT	C. Janes
16:00		Coffee Break	
	16:15	Correlator IPT	J. Webber
	16:45	Computing IPT	B. Glendenning
17:15	**Executive Session**		
	17:15	Garmisch Cost Review and discussion with Steve Beckwith (1 hour)	
	18:15	Review of First Day	
18:45	**Adjourn**		
19:30	**Dinner – All attendees**		

Tuesday January 31

7:45	**Executive Session (optional)**		
8:00	**Project Overview – Part III**		
	8:00	Systems Engineering and Integration IPT	R. Murowinski/R. Sramek
	8:30	Science IPT	A. Wootten
	9:00	Operations	D. Silva
	9:25	NA operations (NAASC)	P. Vanden Bout
9:40		Bio Break	
9:45	**Management**		

AUI management of NRAO/ALMA — E. Schreier
NRAO management of ALMA-NA — A. Russell

12:00 Working Lunch
12:45 Bio Break
13:00 **Breakout Sessions (three parallel)**

a)	Computing	Glendenning/Shepherd/PMCS
b)	Back End	Janes/Ford/PMCS/Beasley
c)	System Implementation	Murrowinski/Sramek/Donoso/Zivick/PMSC

16:00 Bio Break
16:15 **Collect and travel to NTC**
16:30 NTC Tour
17:30 **Executive Session at NTC**
18:30 Debrief w/PM, IPT Leads; assign overnight homework
19:00 **Adjourn**

Wednesday, February 1

8:30 **Executive Session**
9:00 Project responses to variance reports from plenary and breakout sessions
11:00 **Executive session –**
Draft report
13:00 **Closeout – Panel with AUI/NRAO and NSF**
< Working Lunch>
14:00 **Executive Session**
Review and refine written reports for each area
Identify possible follow-up work
16:00 **Adjourn**