MINUTES

Meeting of Engineering Consultants
Radio Astronomy Project

Associated Universities, Inc.
350 Fifth Avenue
New York 1, New York

October 16, 1956

1. Meetings were held on September 25-26-27 to discuss the engineering problems involved in the 140-foot radio telescope program. The first day was devoted to discussions of drive and control problems and consultants on these matters attended. On September 26 there was a broader discussion of structural problems and the meeting was attended by both structural and drive and control consultants. The last day was essentially a working session, to consolidate the results of the first two days and arrive at the specific steps to be taken to lead to the preparation of invitations for bids. The following is a list of those attending. Attendance on September 26 is signified by the absence of a symbol after the name; attendance on September 25 or 27 is indicated by symbols "a" and "b", respectively.

ab	Ashton, N.L.	Univ. of Iowa
b	Ayre, R.S.	Johns Hopkins Univ.
b	Bijlaard, P.P.	Cornell Univ.
a	Brown, T.W.	Lombard Governor Corp.
	Carter, W.O.	Keller Loewer & Assoc.
b	Christensen, N.A.	Cornell Univ.
ab	Emberson, R.M.	AUI
	Feld, Jacob	Consultant, NYC
b	Freudenthal, A.M.	Columbia Univ.
a	Haddock, F.T.	Univ. of Michigan
ab	Heeschen, D.S.	AUI
b	Husband, H.C.	Husband & Company
	Kane, T.R.	Univ. of Penna.
ab	Karelitz, M.B.	BNL
b	Kavanagh, T.C.	Praeger-Kavanagh
	Loewer, A.C., Jr.	Keller Loewer & Assoc.
a	McClain, E.F.	NRL
a	Newton, G.C.	MIT
a	Poitras, E.J.	Consultant, Mass.
	Reintjes, J.F.	MIT
ab	Rule, B.H.	CIT
b	Shore, Sidney	Univ. of Penna.
ab	Silvey, J.O.	MIT
b	Tatel, Howard	CIW-DTM
b	Wilts, C.H.	CIT
a	Lindorff, D.P.	Univ. of Conn.

2. The discussions opened with a review of the desired specifications for the 140-foot telescope, tempered by what was deemed to be technically feasible in the immediate future. It was agreed that except for the matter of sky coverage, the same specifications would apply to all mounts, whether altazimuth or equatorial. It was noted that a compromise might be necessary with limited sky coverage, if an equatorial mount is selected. In no event was any special weight to be given to the use of the 140-foot telescope as a model for larger instruments, although this was recognized as being desirable from an engineering point of view.

Wind Condition	Zero Wind	16 mph Wind
Paraboloid surface	± 1/4"	± 1/4"
Absolute pointing accuracy	± 30"	± 40"
Relative pointing accuracy*	± 10"	± 20"
Tracking accuracy over 15 min time	± 10"	± 20"
Tracking accuracy over 1 hr or more	± 20"	± 40"

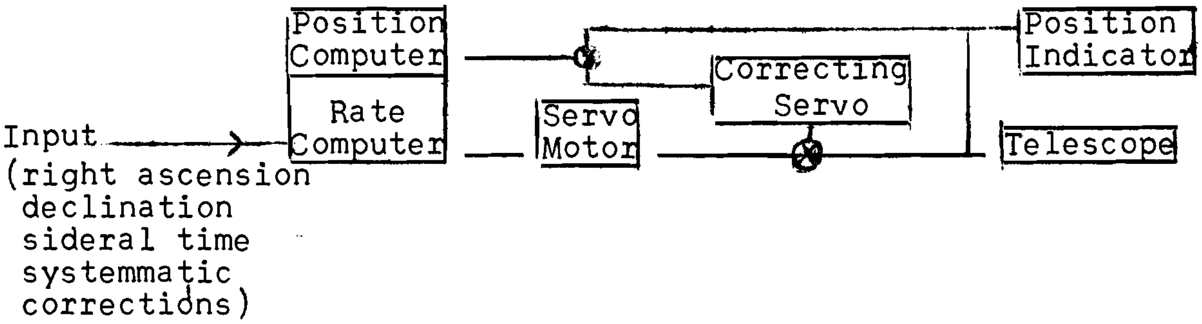
*Relative pointing accuracy is defined as the accuracy with which the telescope can be moved from one point to another point, assuming the subtended angle between points is under 30 deg and that both points are 30 deg or more above the horizon.

A subgroup, composed of Messrs. Haddock, Heeschen, and McClain will look into tracking requirements in more detail.

3. Although no specific experiences could be reported it was the consensus that slewing motors could be either electric or hydraulic; in the former case the motors could be sufficiently well shielded to prevent interference with other telescopes at the site. On the other hand, it seemed best that hydraulic motors be used for the tracking. Again lacking specific experiences, it was the consensus that a friction drive (such as the azimuth drive in the Husband design) could be made to work as well as a gear drive -- there were some worries about grinding the azimuth rails smooth, thermal expansion, etc.

4. Pending the availability of wind data from Greenbank, it was decided to base the specification on two wind conditions (no wind and less than 16 mph), with the implicit understanding that precise observations at very short wavelengths would have to be curtailed if the winds got above 16 mph. After discussion, it was agreed that a wind tunnel test of a detailed model, carefully scaled and constructed, might not be warranted but tests should be made of gross features, e.g. tipping moments and drag against slewing.

5. The discussion of open-loop and closed-loop servo systems brought out that in either it would be desirable to provide a means to introduce simple programming to take out known systematic errors, such as those due to gravity deflections, gear errors, and axis misalignment. Such a system is being used successfully on the Palomar telescopes. Messrs. Poitras, Brown, Rule and Silvey made suggestions for possible servo systems, such as the following:



The same system could be used for either an altazimuth or equatorial mount, but the computer would be very much simplified for an equatorial mount (if only hour angle and declination motions are required). The system would drive the telescope, and ignore the position of the beam relative to the telescope axes. An open-loop servo system could be used with an equatorial mount (provided it were used for hour angle and declination motions only) with systematic corrections introduced through systems of second-order accuracy.

6. Three types of devices were discussed for position sensing: Standard types of synchos, used with precision gears in order to give the required precision; coded disks, which would be particularly useful if digital computers are employed; and the Farrand inductosyn,which is a single unit that is equivalent to a highly geared synchro.

7. The computer for an altazimuth telescope (or for both altazimuth and equatorial telescopes, if some third coordinate system, such galactic, is employed) should be either continuous or, if by steps, within a few hundredths of a second of real time. Computers, such as the IBM 704 could meet the desired accuracy and speed. In use they require regular maintenance but in such service make only about one error per month. The IBM 701 would be slower (e.g. 0.04 second) but might be adequate. On a rental basis these machines might cost $20-35,000/month. However, these machines are far more versatile than needed, and less costly equipment might be had. Prof. Lindorff agreed to look into this problem in more detail.

8. The Farrand Optical converter proposal promised an over-all accuracy of 2½ seconds of arc. No information was available on cost details but the impression was that Farrand did not consider this a development item. AUI will look into this further.

9. Six telescope designs were discussed on September 26: altazimuth designs by Feld, Husband, and Kennedy and equatorial designs by Feld, Husband, and Tatel. Detailed drawings were lacking for two of the equatorial designs, but the group was convinced that a satisfactory design was technically feasible. Discussion brought out the

importance of a dynamic balance (for other than a no wind condition); that low friction is important for any tracking motion (wind gusts in the direction of a synchronous hour angle drive essentially requires a "start-up" when the wind stops); and the desirability of a large working radius for the drive and control motors.

10. The Feld equatorial design was critically reviewed, particularly with respect to the probable rigidity of the reflector as compared to the Husband and Kennedy reflectors, and bearing and drive problems were discussed. There was doubt that oil-pad bearings could be substituted for the commercial bearings on the polar axis unless the design was modified considerably. Mr. Tatel described the equatorial design conceived by him and his colleagues at the Dept. of Terrestrial Magnetism. This mount has the particular advantage of a large radius for the application of the drive and control.

11. Mr. Husband reviewed his work with the Manchester 250-foot telescope. He has found that the cost of the structural steel is about one-third of the cost of the telescope, including foundation and drive. He proposed an equatorial design with a polar axis arrangement very much like the 200-inch Palomar telescope.

12. In summary, a drive and control system, as proposed by Mr. Poitras can be utilized from either an altazimuth or equatorial telescope, the same component parts being used except for the computer, which generally can be much simpler for an equatorial telescope. Mr. Silvey agreed to undertake a uniform price estimation of the component parts of a drive and control system, with Prof. Lindorff supplying a detailed examination of digital computers and Drs. Emberson and Heeschen supplying details of the Farrand equipment.

13. It was agreed that price estimates on several types of telescopes would be prepared, the work being divided into two parts:

    A. Drive and Control, to be coordinated by Mr. Silvey of the MIT Servomechanisms Laboratory, and

    B. Structure & Mechanisms, to be coordinated by Dr. Kavanagh of Praeger & Kavanagh, New York.

    It is necessary to agree on the point of division between A and B. Task A will include all motors, position sensing devices, indicators, computers, amplifiers, including any precision gearing needed for position take-off but stopping at the pinion gear of the drive and/or tracking motor(s), whether these be applied to a single large gear (e.g. the azimuth gear in the Feld altazimuth design) or to several bogie wheels (e.g. as in the Husband design).

    Task B would include all construction: a rough estimate on a foundation carried 20 feet below grade to rock; any ground level construction such as circular tracks or bearings; above level structures, whether metal construction as in the Feld and Husband altazimuth designs or with considerable amounts of concrete as in the Kennedy altazimuth and Feld equatorial designs; bearings, shafts, and gears up to the point of application of power from the slew and/or tracking motors, and all parts of the reflector including a support for rf-feeds and receiver components at the focus of the paraboloid.

14. Dr. Kavanagh has agreed to estimate prices on four telescope designs: The Feld, Husband, and Kennedy altazimuth designs and the Feld equatorial design. Messrs. Husband and Kennedy have agreed to estimate prices on their respective altazimuth designs and also to estimate, on the same basis, what comparable equatorial designs would cost, with two assumptions: first, that the equatorial mount must give essentially total hemispheric coverage and, second, that the equatorial mount provide a limited sky coverage. For the purpose of these estimates, the following should be adopted:

<u>Essentially total sky coverage</u>: As a minimum, to reach along the horizon from 30° north of east, through the south point to 30° north of west; from the minimum horizon described above up to the pole; and the circumpolar region (assume a latitude of 39°) including the north point of the horizon. Regions desired but not required would thus be along the horizon northward from 30° north of west and 30° north of east and extending upward toward the pole in the triangular areas bound by the circumpolar circle of radius 39° and by the great circles from the pole through the horizon points 30° north of the east and west points, respectively.

<u>Limited sky coverage</u>: As a minimum to reach within 3° of the horizon from the east point, through south to the west point; the region of the sky upward from the above-described horizon, bound by great circles from the pole through the east and west points, respectively.

15. The prices estimated by Messrs. Husband and Kennedy probably will not be based on the same unit cost scales, nor would they be identical with the scales adopted by Dr. Kavanagh. But Dr. Kavanagh will have estimated prices on the Husband and Kennedy altazimuth designs and, thus will be able to establish factors to reduce all Husband and all Kennedy estimates to the same basis as the Kavanagh estimates. Hence, it will be possible to prepare a table of homogeneous price estimates on Feld, Husband, and Kennedy altazimuth mounts; on Feld, Husband, and Kennedy equatorial mounts with essentially total hemispheric coverage; and on Husband and Kennedy equatorial mounts with limited sky coverage.

Summary of NY Meetings Sept 25-27

Tues, Sept 25: Drive & Control Problems

I Tolerances for 140 ft alt-azimuth Telescope

The following tolerances were adopted for purposes of discussions of drive & control problems

A Ideal conditions → no wind, no temperature gradients
surface ± 1/4 inch
absolute pointing accuracy ± 30" in each coordinate
rel pointing accuracy (between two objects ≤ 30° apart on sphere & > 30° elevation) ± 10" in each coord.
tracking accuracy:
short time: (15^m) - 10" in each coord.
long time: (1^h) - 20" in each coord.

B Normal conditions → winds up to 16 mph
surface ± 1/4 inch
absolute pointing accuracy ± 40" in each coord.
rel pointing accuracy ± 20" in each coord.
tracking accuracy
short time (15^m) ± 20" in each coord
long time (1^h) ± 40" in each coord

It was agreed that the desirable tolerances for tracking need further thought and amplification. Haddock, McClain & Heeschen will undertake this. It was also agreed that the designer needs more wind data than that specified above. After wind data at Greenbank has been obtained, the "normal" wind conditions will be defined more precisely. In particular, it was decided that the designer should have an rms variation in wind force.

The above tolerances were also adopted for the equatorial mount.

II Control System for alt-az

It was generally agreed that the alt-azimuth design requires a closed-loop servo system. The loop however would actually include the antenna itself. The servo system would correct all gearing & drive errors, but would not correct for random errors, such as those due to wind gusts, occuring beyond the output gearing. To include the antenna in the servo system would require some sort of stable platform, the developement of which would be too costly & complex a job.

Any ~~control~~ drive & control system, whether it be open or closed loop, can be very simply programmed to take out known systematic errors due to gravity deflections, gear error, errors in axis alignments and the like.

Mr Poitras suggested the possibility of using a closed-loop velocity servo, in which the driving rate would be servo'd against a standard. A position servo would be used to make differential corrections.

III Coordinate Conversion - alt az

A) digital computer:

It was agreed that a digital computer could easily be obtained which would have the necessary speed and accuracy.

An IBM 704 could perform the $(\alpha, \delta) \to (A, h)$ conversion in 20 milliseconds. It rents for about $40,000 per month. It is very reliable but requires constant maintenance.

IBM 650 probably is not fast enough → it can perform the required computations in ~ ½ sec

The general consensus was that a computer could do the job, but it would have a high initial cost, a high maintenance cost, & would be a complex & touchy piece of equipment

B analog converter.
Farrand makes a converter which they claim has the necessary accuracy. Cost & reliability of this instrument are not known. AUI will have further discussions with Farrand.

The general conclusion was that a digital computer is too expensive, too complex, & too subject to uncertainties to be a desirable portion of a telescope control system. It was ~~for~~ pointed out however that a computer could do it if it became necessary.

IV Drives for alt-az
The consultants agreed that

1) use separate drives for track & slew, because of the very different power & precision requirements

2) either DC motors or hydraulic drive would be suitable for tracking. Disadvantage of DC motor is need for shielding. Disadvantage of ~~AC~~ hydraulic system is ~~~~ greater maintenance problem

3) either AC or DC motors ok for slewing. DC motors might have to be shielded so as not to interfere with other telescopes in the vicinity

II Drive & Control for Equatorial Mount

A. drives & control system much simpler with equatorial telescope. Open loop system could probably be used.

B. Could go use synchronous motor drive, with frequency, ∴ speed, ~~mag~~ controlled by simple mechanical system to take out any systematic errors due to gears, axis misalignment, deflections. This is the way the Palomar telescopes are.

Wed. Sept 26

Much of this day was spent discussing the general philosophy of the design of large radio telescopes. Husband described a 140 ft equatorial design & Tatel described the OTM design. There was general agreement that both designs were very sound & would perform well

The principal features brought in the general discussion were:

1) high driving accuracy & protection against high winds both require that the dish be held & driven with large radius gears

2) the dynamic characteristics may be much more important than static

3) wind tunnel tests of models are highly desirable

It was decided that wind tunnel tests should be made for

a) drag & torque tests in all aspects of the dish
b) flutter

Elaborate models are unnecessary

The models should be as large as possible but should not be any greater than about ½ the diameter of the wind tunnel throat. Scale reductions of 30 to 1 to 60 to 1 can safely be used to extrapolate results.

It was decided to postpone wind tunnel tests until the ~~number of~~ different design possibilities had been reduced to a reasonable number.

Dr Feld's equatorial design was discussed at some length. ~~The following points were brought out~~:

~~1) the adjustments provided for the surface of the dish are not adequate & the surface is essentially determined by the grid, for which there is no adjustment~~

2) The ring girder support at the edge of the dish is not enough. There is point support in

A large number of detailed criticisms were made. It was generally agreed that his dish design is not satisfactory & that his mount needs very considerable revision before it is satisfactory.

There was no discussion of the three alt-azimuth designs

Thurs Sept 27

A good estimate of the initial cost, maintenance cost, & reliability of a digital computer for coordinate conversion is needed, Silvey will do this

The desirability of getting an independent, comparative estimate of the costs of various designs was stressed. Kavanaugh will get price estimates for 3 alt-az designs & Field equatorial design.
Husband will provide estimates for his alt-az & equatorial, & another equatorial with greater sky coverage
Kennedy will provide estimates of Theis alt-az & equatorial telescopes, & a separate estimate for the reflector alone.

ASSOCIATED UNIVERSITIES, INC.

350 Fifth Avenue
New York 1, New York

October 31, 1956

MEMO TO: Ad Hoc Committee on a 140-foot Equatorial Telescope Design

FROM: Richard M. Emberson

SUBJECT: Organization; First Meeting to Discuss the General Characteristics

1. Following the September 25-27 meeting of consulting engineers and an October 16-17 meeting of the AUI Advisory Committee on Radio Astronomy, arrangements have been made with Prof. Ned L. Ashton to undertake an equatorial design for the 140-foot telescope, with the advice and assistance of a special ad hoc committee. Dr. Thomas C. Kavanagh has agreed to serve as chairman of the committee, which is kept small in order to be of manageable size and yet is believed to have expert representation for the major problems involved in the design. The following are being asked to serve on the committee and are listed here in three groups having general structural, drive and control, and observational interests, respectively:

P.P. Bijlaard	J.O. Silvey	J.G. Bolton
N.A. Christensen	D.P. Lindorff	F.T. Haddock
A.M. Freudenthal	E.J. Poitras	E.F. McClain
	B.H. Rule	H.E. Tatel

In addition, Dr. Heeschen and Mr. Karelitz may be counted on to work closely with the Committee, and other consultants can be called in if special problems arise.

2. The general specifications for the telescope, as proposed at the September meeting and reviewed in October are as follows:

Equatorial mount to provide limited sky coverage as a minimum, bounded by a great circle from the pole to the east point of the horizon, along the horizon through the south point to the west point, and along a great circle from the west point to the pole.

A minimum radius of fifty feet shall be provided for the application of the drive and controls for motions about the polar and declination axes. An oil pad bearing system shall be provided for the polar axis.

Other specifications are given in the table below:

Wind Condition	Zero Wind	16 mph Wind
Paraboloid surface	± 1/4"	± 1/4"
Absolute pointing accuracy	± 30"	± 40"
Relative pointing accuracy*	± 10"	± 20"
Tracking accuracy over 15 min. time	± 10"	± 20"
Tracking accuracy over 1 hr. or more	± 20"	± 40"

*Relative pointing accuracy is defined as the accuracy with which the telescope can be moved from one point to another point, assuming the subtended angle between points is under 30 deg and that both points are 30 deg or more above the horizon.

Although the Advisory Committee at the October meeting expressed an interest in a surface tolerance for the paraboloid of 1/8 inch, unless it is clear that such a tolerance can be obtained with no significant increase in cost, we must retain the original specifications of 1/4 inch.

3. The first meeting of the ad hoc committee has been scheduled for 9:30 a.m., Wednesday, November 14, 1956 in the AUI Office Room 6920, Empire State Building. It is anticipated that a one-day meeting will be adequate. Please advise at once if you wish hotel reservations, assistance with transportation, or a travel advance. A form is enclosed for your convenience.

4. The purpose of the first meeting is to review all available design information in order to select the most promising characteristics for incorporation in the AUI equatorial design. Should anyone wish to have material duplicated by us for distribution at the meeting, please have the material in our hands as early as possible the preceding week. Sketches should be in carbon ink or black pencil; most blue inks and some non-carbon black inks do not copy well, if at all.

copies to ad hoc committee
Ashton, N.L.
Dunbar, C.F.
Heeschen, D.S.
Karelitz, M.B.

enc. Reservation Form