CONTROL SURVEY STUDY FOR LRIS

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PREFACE

In order to make our extensive series of technical reports more readily available, we have scanned the old master copies and produced electronic versions in Portable Document Format. The quality of the images varies depending on the quality of the originals. The images have not been converted to searchable text.

CONTROL SURVEY STUDY FOR LRIS

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FOREWORD

This Technical Report was originally prepared by a team of faculty members in the Department of Surveying Engineering at the University of New Brunswick (UNB), for the Planning and Projects Section, Land Registration and Information Service (LRIS).

Essentially, the purpose of this report is to answer the question: "Are the new developments in positioning technology sufficiently advanced that LRIS should modify its maintenance and densification program and, if so, in what way?"

The study was planned on the assumption that a transition to new technology was still well in the future. However, as the study progressed, it became apparent that the technology was developing much faster than had been assumed and, hence, less emphasis should be put on the assessment and critique of the present network. It also became apparent that, in addition to a long-term scenario, a transition plan should be developed.

Accordingly, two workshop sessions were held instead of one. On 21 October 1985, a seminar/workshop was held at which statistics on network maintenance and densification were presented by staff of LRIS, and a wide-ranging review of recent developments and trends in positioning technologies was presented by the faculty members of the Surveying Engineering Department, UNB. A transcript of these presentations and discussions is in Appendix II.

On 12 March 1986, another workshop was held at which the transcript of the October meeting was reviewed, developments since October were discussed, and a consensus was reached on a long-term scenario and on the strategy for the transition period. That consensus forms the basis for this report.

Angus C. Hamilton

CONTROL SURVEY STUDY
FOR LRIS

EXECUTIVE SUMMARY

A review of GPS technology indicates that with differential methods (two receivers operating simultaneously) relative positioning to better than one part per million should be achieved consistently in a 15 minute observation period by about 1990. GPS has some distinct advantages over conventional (e.g., total station) technology.

- Three coordinates (latitude, longitude, and height) of a new point can be determined by occupying only the new point and one reference station; the two receiver sites need not be intervisible.

- As relative precision is one part per million or better, stations in the control network can be several tens of kilometres apart. Thus, instead of some 40,000 control stations, only a few hundred would be needed for the Maritime Provinces.

Nevertheless there are some concerns about GPS technology.

- The full constellation scheduled for 1989 is 18 operational satellites, but at present—March 1986—seven protoypes are providing reception for about five hours per day. There is concern that this schedule may be delayed; however, there is no reason to expect a significant delay.

- GPS is a military system, and there is the possibility, though remote, that the U.S. Department of Defense could try to curtail its availability to non-military users. Such curtailment is unlikely to prevent the use of the system for differential positioning.

- The cost of GPS receivers is such that for widespread use it is not yet competitive with that of other positioning technology; however, there is fierce competition for the market and, as with other electronic products, costs are coming down rapidly.

A scenario is presented for the time when the full complement of satellites is in place, the cost of a system has become comparable to that of other positioning systems ($10,000 to $20,000), and conversion factors from the ATS network to a GPS network are available.

Each survey firm will maintain one receiver as a monitor at their office/laboratory (or they will contract for this service) and will provide each survey party with a mobile receiver. Each party will then be able to obtain coordinates by setting their mobile unit up at a station for a few minutes. The duration of observing will depend on the precision required; the farther from the monitor the longer it will take to get the required precision. This should save the surveyor some time because he will not have to locate and occupy a pair of control stations close to his project. It will relieve LRIS of the cost of maintaining a dense network of control stations.

This scenario can only happen if:

- *A sparse (50 to 70 km), but very precise (≈ 1:1,000,000) GPS reference framework of primary stations is in place, and there are "local scale factors" to connect ATS77 coordinates to GPS network coordinates.*

- *Most surveyors have GPS receivers of their own, and the others have ready access to receivers as required.*

In fact, unless LRIS gives considerable impetus to the conversion to a GPS reference framework, the widespread use of GPS in the Maritime Provinces may not occur for many years.

It is recommended that LRIS embark immediately on a GPS familiarization program and that, subject to its verification of the general conclusions in this report, it proceed with a five-year GPS conversion program.

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ACKNOWLEDGEMENTS

The financial support of the Land Registration and Information Service is gratefully acknowledged as is the whole-hearted cooperation of all those who participated in the workshops and those who responded to questions about the control network in the Maritime Provinces.

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1. INTRODUCTION

Survey control provides the framework for all mapping and for most of the land surveys in the Maritime Provinces. Although there is now survey control virtually everywhere it is needed, this was not always the case. In fact, although there had been some control for large scale mapping in the major cities and a start had been made on a systematic densification program in New Brunswick, it was not until federal funding for APSAMP (Atlantic Provinces Surveying And Mapping Program) became available in 1968 that a systematic control densification program got under way. This program continued under LRIS, and now a network of some 49,000 stations is in place.

Unfortunately, approximately 2% of the monuments are destroyed each year; if a network is to be kept in good order, these points must be replaced and new points (approximately 1% each year) must be established in developing areas.

Prior to the availability of the network, land surveys were referenced only to old boundary markers; consequently, legal survey plans rarely could be overlaid on and matched with planimetric/topographic maps. Gradually as the network became available, land surveyors began to connect their surveys to control stations and, hence, property surveys and planimetric/topographic maps are becoming consistent. This is a prerequisite for a modern land information system.

Even though the main thrust of this study is an assessment of new positioning technologies and the development of a scenario for the long term, it was felt that some independent assessment of the present network was necessary. To get an objective indication of the quality of the network, the data base was searched for lines on which recent distance measurements had been made; these were then compared with measurements made prior to the 1977 re-adjustment. Comparisons on 2463 lines showed that on 1531 of these the difference between the old and recent measurements was less than 1:50,000. Another 728 lines had differences less than 1:10,000; there were some larger differences, but these were almost all on short lines. A few with apparent blunders were drawn to the attention of the Control Survey Section in Summerside. Although far from being a definitive analysis of the network, it was sufficient to indicate that the quality of the network generally is good. These data have been turned over to Mr. Wroblewicz.

As land surveyors are by far the most frequent users of the network, their opinions were sought and, as questionnaires quite often conceal rather than reveal information, we limited our inquiry to informal discussions with a few land surveyors. From these discussions the following statements were paraphrased:

> *If there wasn't a control network, I'm not sure I'd continue in practice.*
>
> *In my area the maintenance program was completed about three years ago and since then we very rarely find any significant discrepancies.*
>
> *Even if there are boundary markers quite close to a new job, our firm always goes back to a pair of control monuments to start a survey; we have found that the short (30") bars used for boundary surveys are not stable enough to tie work to. Distances aren't too bad but we find that azimuths may be off by a minute or more and for a long line this isn't good enough.*
>
> *Please, please, don't change the datum again. Technically it is no problem but our*

clients suspect us of skulduggery or incompetence if we change their coordinates. We can't afford the time to explain and they won't take the time to listen to the reasons why coordinates should be changed.

On one job, I found a bar that had been moved by the land owner. Using coordinates I was able to restore it very, very close to its original position.

The above quotations are paraphrased from discussions with Ken MacDonald, Burt Cain, Walter Rayworth, and Bernard Justason.

From these comments and from the comparisons above, it is apparent that the network is of good quality and that it is meeting the needs of its main users. There is concern, however, among users and among LRIS regional surveyors that cyclical maintenance and densification does not ensure that control is where it is needed when it is needed. From this very superficial investigation, we raise the following question:

Is there not a method by which the land surveyor's intimate knowledge of the community and his cost-conscious resourcefulness can be used to improve the effectiveness of the network and to reduce costs?

Although the network is clearly serving its purpose satisfactorily now, it is costly to maintain; currently it is costing more than $600,000 per year. Thus it behooves prudent managers to look for more cost-effective ways to maintain the present network and at the same time to explore new technologies for less costly, and possibly more effective, alternatives to the present system.

Accordingly, in the first stage of this study, a seminar/workshop was held (21 October 1985) at which statistics on network maintenance and densification were presented by LRIS staff and a wide-ranging review of recent developments and trends in positioning technologies was presented by S.E. Department faculty members. A transcript of these presentations and discussions is included as Appendix II.

On 12 March 1986, another workshop was held at which the transcript of the October meeting was reviewed, developments since October were discussed, and a consensus was reached on a long-term scenario and on the strategy for the transition period. That consensus forms the basis for this report.

One of the items on which there was **consensus** was that ***GPS is the only new technology that is both sufficiently promising and sufficiently advanced to warrant investigation in considerable detail at this time.*** There are other technologies that are promising and there are other technologies that are quite advanced, but GPS is the only one that is both. Information on some of the other technologies is available in the transcript of the first seminar/workshop (Appendix II).

2. GPS (Global Positioning System)

The Global Positioning System is the second generation of satellite navigation systems; the first generation was the Transit satellite Doppler navigation system. Both systems were designed for the U.S. Department of Defense for military navigation. Resourceful researchers adapted Transit for geodetic control, and it has been widely used throughout the world and especially in Northern Canada. With Transit, one satellite at a time is tracked to give a "line of position," then another satellite is tracked to give another line of position, and so on. With GPS, several satellites are tracked simultaneously, hence an almost instantaneous position can be obtained.

GPS has two modes: in one mode, one GPS receiver can be used for "absolute" positioning (positioning in the same reference framework as the satellite orbits); in the other mode, two receivers are used for differential positioning (positioning an unknown point with respect to a known point). Differential (relative) positions can be determined much more accurately than absolute positions (Fig.1) and hence only differential positioning is considered for survey applications.

In Fig. 1, the relative elevation as well as the relative latitude and longitude of one point with respect to the other can be determined quite precisely **without the requirement for inter-visibility.** All that is required is a clear sight from about 20° above the horizon in all directions. In differential mode, GPS could be used for traversing in place of a "total station" but, as will be discussed subsequently, this would not be using its potential to the best advantage.

As indicated in Fig. 2, GPS is much more precise than either Transit satellite Doppler or Inertial Survey Systems. Although it is not more precise than conventional terrestrial techniques at short distances, it is much more precise at longer distances. The illustration shows Satellite Laser Ranging and Quasar Very Long Baseline Interferometry as more precise, but it does not show that these methods are much too complex for survey purposes.

The basic GPS concept is shown in Figs. 3 and 4. As indicated in the figures, the high precision is achieved because many error sources are common to both receivers. It is implicit, however, that ranging to several satellites must be done simultaneously by both receivers; thus several satellites must be visible to both receivers. At present (March, 1986) only 7 GPS satellites are in service (Fig. 5) and hence an adequate configuration is visible for only one 5-hour period each day.

When fully operational in 1988 or 1989, there will be 21 satellites (Fig. 6) of which 18 are scheduled to be operational all the time.

In Fig. 7, those parameters relevant to this study are listed for 1986, 1990 and "ideal". From this list we see that in 1986 the accuracy/time trade-off is adequate for surveying (1 ppm in 1 hour; 10 cm in 1 minute) and that by 1990 it is projected to be better (0.01ppm in 15 minutes) than would be required for most survey applications.

Although the 1986 cost is beyond the means of the "average surveyor," the projected 1990 cost range is comparable to that of good EDM equipment now.

From this data, it is apparent that:

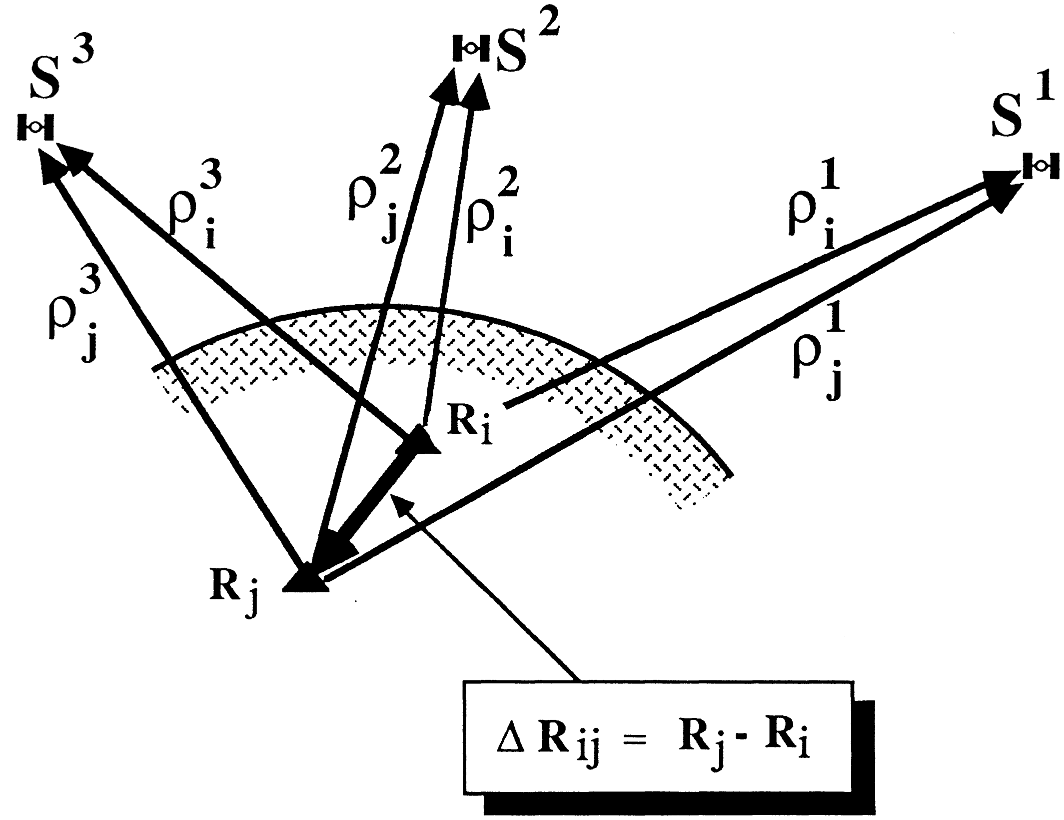
(a) ***The accuracy and the observing time are already adequate for survey applications, and further improvements are expected by 1990.***

(b) ***Even with some delays, the system is likely to be fully operational by 1990.***

(c) ***The cost of receivers is already competitive for specialized applications (such as for positioning township corners in northern Alberta) and the projection for 1990 is that the cost will be comparable to that of other good***

FIG.1

RELATIVE POSITIONING USING PSEUDO-RANGES



Relative positions ΔR_{ij} are determined more accurately than "absolute" positions R_i and R_j, since several sources of error will be common at both receivers, and will cancel.

FIG. 2

NEW TECHNOLOGIES
PRECISION VS. DISTANCE

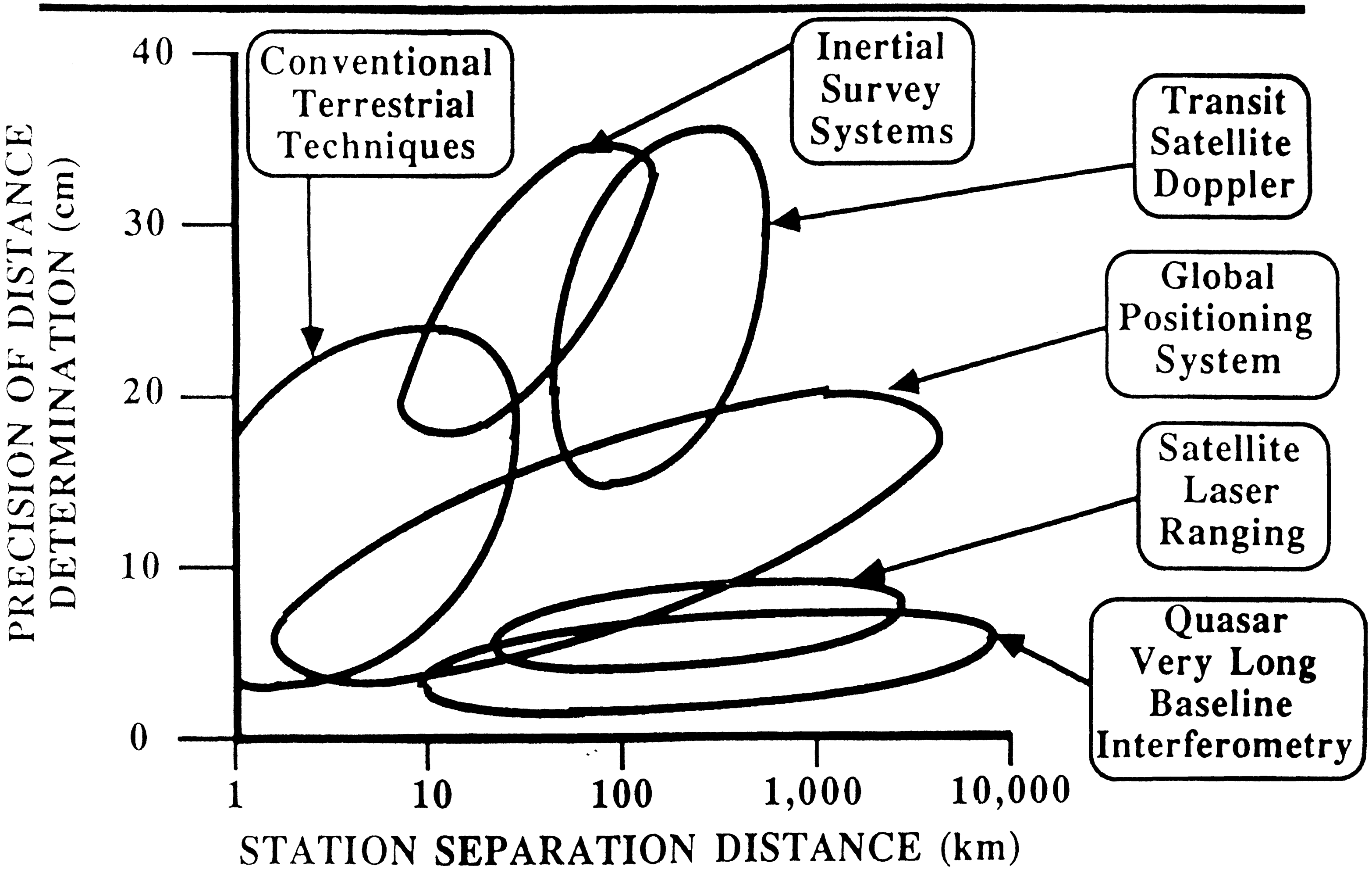
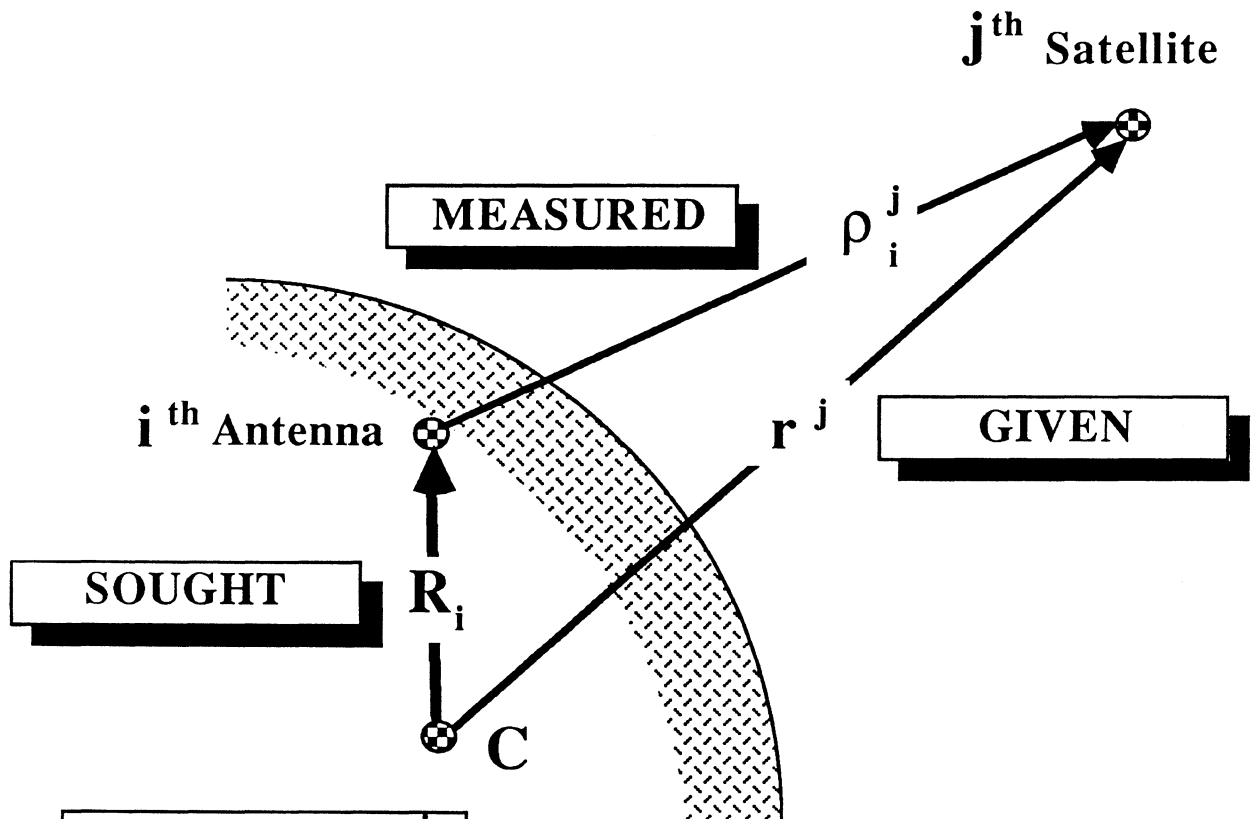


FIG.3

BASIC CONCEPT OF SATELLITE POINT POSITIONING



$$R_i = r^j - \rho_i^j$$

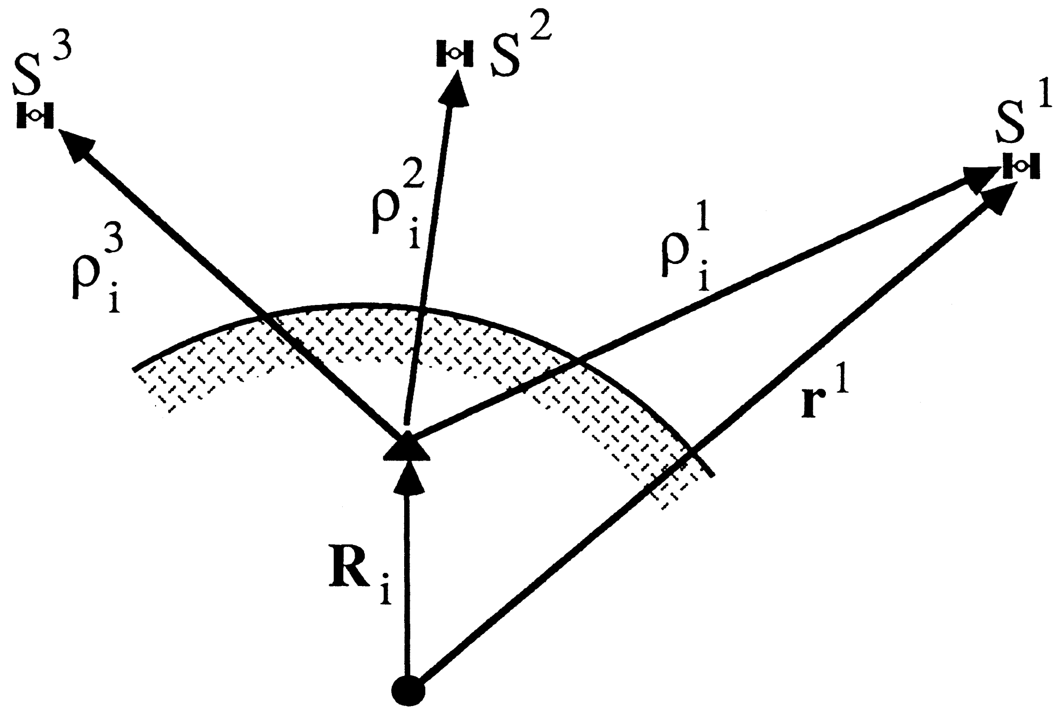
R_i is the position vector of the i th antenna

r^j is the position vector of the j th satellite

ρ_i^j is the range vector between the two.

FIG.4

SATELLITE MULTI-RANGING



SCALAR EQUATION

$$\rho_i^j = \| \mathbf{r}^j - \mathbf{R}_i \|$$

Measure LENGTHS ρ_i^j to all satellites simultaneously

LIMITATIONS

Any error in $\mathbf{r}^j$ will result in an error in $\mathbf{R}_i$

Propagation errors will cause errors in ρ_i^j

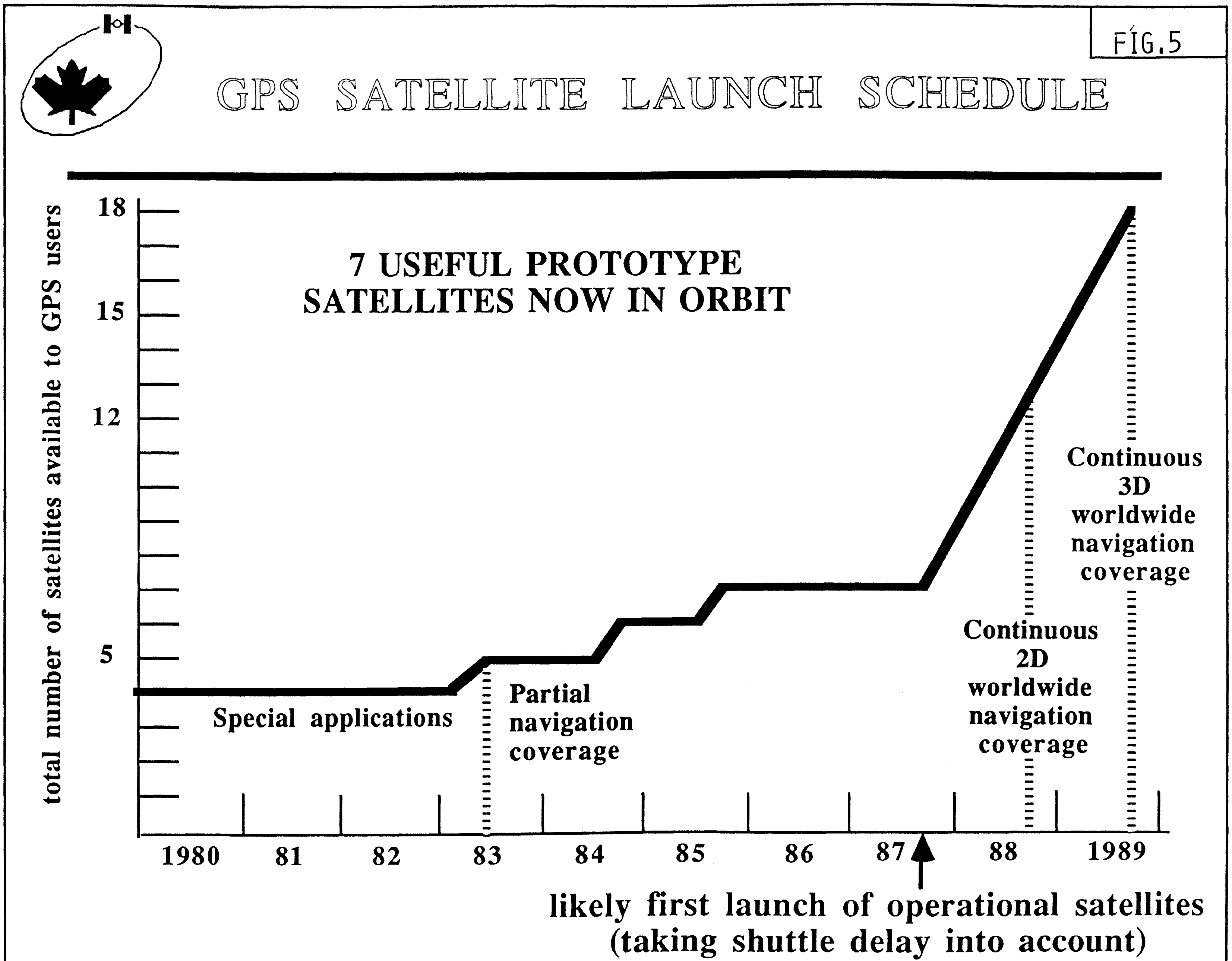
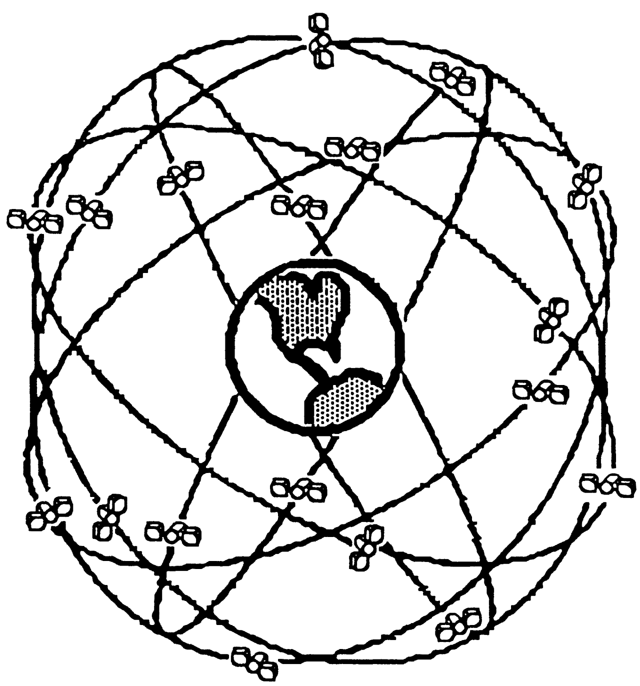


FIG.5
GPS SATELLITE LAUNCH SCHEDULE
7 USEFUL PROTOTYPE SATELLITES NOW IN ORBIT
total number of satellites available to GPS users
18
15
12
5
Special applications
Partial navigation coverage
Continuous 2D worldwide navigation coverage
Continuous 3D worldwide navigation coverage
1980
81
82
83
84
85
86
87
88
1989
likely first launch of operational satellites (taking shuttle delay into account)

FIG. 6

GPS CONSTELLATION IN 1990



- 18 satellites, plus 3 active spares
- 6 orbit planes
- 12 hour period
- 20,000 km height
- (almost) full coverage
  (24 hours per day everywhere in the world)

FIG.7

GPS LIMITATIONS

	1986	1990	Ideal
COST	$20k - $300k	$5k - $20k	**$10**
WEIGHT / BULK	5kg - 300kg	hand held	**wrist locator**
POWER SUPPLY	AC external DC internal DC	internal DC	**watch battery**
OBSERVING TIME	10 min-hours (1 min)	15 min (1 min)	**milliseconds**
REAL TIME ?	No	Yes	**Yes**
ACCURACY	< 1 ppm (10 cm)	0.01 ppm (few cm)	**1 mm**
		?	**? ?**

quality terrestrial equipment.

This leads to the **conclusion** that:

(a) ***GPS technology is going to be available much sooner and to have far more impact than was envisioned as recently as one year ago.***

A scenario for positioning in the long term and suggestions for a familiarization program and a transition program follow.

3. SCENARIO FOR POSITIONING IN THE LONG TERM

Even with the 1986 accuracy/time trade-off (see 2 above) it is apparent that present accuracy standards can be met or exceeded by setting the mobile receiver up for a very few minutes (see Fig. 4) at any unknown point within several kilometres of a base at which a monitor receiver is operating. In Appendix I, it is shown that precision of 5 cm could be maintained up to 35 km from the base station. If this precision is acceptable, then one station will serve as control for an area of some 4000 km^2 ($\pi\ 35^2$), whereas with the present network, several hundred control stations are needed for 4000 km of typical rural countryside. Thus, for the three Maritime Provinces, instead of some 49,000 control stations, only a few hundred control stations would have to be maintained by LRIS.

Operationally, the big advantage of differential GPS over conventional positioning technology is that intervisibility between mobile and monitor is not required. It is, however, essential that both stations receive transmissions from several satellites simultaneously, and that at each station there be a relatively unobstructed view of the sky (at least above 20°). Without the need for intervisibility, the surveyor in the field can set the mobile directly on the point for which he wants coordinates; this eliminates the need to search for and occupy a pair of control points at the start and at the end of a traverse.

For this scenario, the long term is defined as:

(a) after the full GPS constellation is available, and

(b) all those involved in positioning either have receivers of their own or have ready access to receivers; this imples that the cost of a pair of GPS receivers is comparable to or less than the cost of a "total station," and

(c) after a GPS datum has been established and there are "local scale factors" for converting ATS77 coordinates to GPS datum coordinates.

There are at least three ways that surveyors might meet condition (b) above:

(a) Base/monitor stations, computation facilities, and mobile receivers could be maintained by LRIS; mobiles could be "signed out" on a user fee basis by surveyors as needed.

(b) Base/monitor stations and computation facilities could be maintained by LRIS as a service to surveyors; surveyors would have their own mobile receivers or have a standing arrangement to get one when needed.

(c) Consortiums of surveyors in each region could share the cost of a base/monitor station and computation facilities; each surveyor would have one or more mobile receivers.

(e) Each survey firm could have enough equipment to be completely independent; one receiver would be set up as a monitor on a primary station at their headquarters.

Which of these alternatives will turn out to be preferable in the long term is a question that need not be addressed now; these alternatives have been spelled out here simply to show that the cost of equipment, *per se,* need not delay the implementation of GPS technology.

It is implicit, however, that all the surveyors' "base" stations must be part of a network of much higher precision than the present network. If the surveyors' bases are not in the same very precise network, discrepancies between adjacent surveys will occur (see Appendix II) just as they sometimes do now.

If a precise network is not available, the surveyor will have to occupy two or more control stations near each project and, in effect, use GPS as a "super-EDM". This type of use will not be cost-effective. If this type of use were to be the "norm" there would be no incentive for surveyors to acquire GPS receivers. In other words, the establishment and adoption of a new precise network must occur before LRIS can be relieved of its commitment to maintain its dense control station network.

Needless to say, coordinates defined by GPS will not be compatible with ATS77 coordinates. This is because the accuracy of the ATS77 network is approximately 1:50,000, whereas the GPS measurements will be approximately 1:1,000,000. Thus for a 10 km distance, the ATS77 precision is approximately 20 cm, whereas the comparable GPS precision will be 1 cm or less. Therefore, the existing network of first-order accuracy could not be utilized as the network of base GPS stations unless it would be remeasured.

For property surveys, although no two jobs are quite the same, there are several broad categories; a scenario on several of these follows:

(a) ***No boundary markers, no ties to control.*** In this situation the traditional search for evidence will be necessary. When the evidence has been found, the GPS receiver would be set up at two or more corners for a few minutes.

(b) ***One or more markers but no ties to any control.*** Remaining points would be established by traditional methods then, as in (a) above, GPS coordinates would be obtained.

(c) ***No markers but ATS77 coordinates available in some corners.*** In this case, a local "conversion factor" would be needed; presumably the establishment of this local conversion factor would be a joint effort by LRIS and the users in each vicinity. Using the conversion factor, the location of the corners would be found by offset from a "trial" GPS position.

(d) ***Some markers and coordinates in an older sytem.*** As in (c) above, a conversion factor would have to be found or derived.

(e) ***GPS coordinates already available; markers may or may not be found.*** As in (c) above, use "trial" position, if necessary.

For each project, GPS coordinates would be logged for at least two boundary points and sent to the data base. It is implicit that, to minimize confusion in the data base, strict adherence to an orderly numbering system would be essential.

Although at first it may appear that the main benefit of this system to LRIS will be in the reduced network costs, it is probable that the major impact will be on the land information data base. When it becomes a relatively simple matter to get very precise coordinates for man-made and for natural features, as well as for boundary points, then it will be possible to establish and maintain an up-to-date coordinate data base. Users can then access this data base to get whatever "map" data they require; sometimes it will be boundaries but much more frequently it will be man-made features (buildings, roads, bridges, hydrants, man-holes, poles, etc.). Thus the digital planimetric mapping now underway can be regarded as the "initial lift" which, in time, will be continuously up-dated.

Conclusions:

(i) ***The procedure outlined above offers two distinct advantages over conventional methods:***

- *(a)* ***The surveyor in the field will not have to find and occupy any control stations.***
- *(b)* ***LRIS will not have to maintain a dense network of control stations.***

(ii) ***The procedure outlined above can only be implemented and the advantages realized if a new, sparse, but very precise reference network is established and if "local scale factors" maintained by LRIS are available for converting all ATS77 coordinates to the GPS coordinate system.***

Suggestions for a sequence of steps by which LRIS staff can become familiar with the new technology, verify the above conclusions, and prepare for an orderly transition to take advantage of this new technology follow.

4. TRANSITION PROGRAM

From the tempo of development reported in 2 above and from the scenario outlined in 3 above, it is apparent that a well planned transition program is necessary. There are several aspects to consider.

(a) Familiarization with and planning for the new system.

(b) Subject to verification of these conclusions in (a) above, preparation for an orderly transition to a GPS-determined reference framework.

(c) Management of the existing system until it is superseded by the new system.

4.1 Familiarization with the New Technology

From 2 above and from the appendices, it is clear that this is a complex technology and that it is developing very rapidly. Although, in time, it will become a "black box", it is still far from that stage. Until it does mature, potential purchasers need to know the principles and the practical problems at least well enough to "know what questions to ask" and to know when they are getting realistic answers.

Thus, it is **recommended** that:

(i) LRIS second some people to collaborate with UNB's research group on an evaluation project that is scheduled for July 1986.

Some of the questions that can be addressed on this project are:

(a) What training will be needed for field work?

(b) What training will be needed for doing the computations and for establishing the precision of the results?

(c) What spacing will be needed between primary stations in the new network? (A preliminary analysis is included as Appendix I)

(d) Will any changes in boundary survey procedures be necessary when property surveys can be tied to control without occupying any nearby control stations? Will any changes in regulations be necessary?

4.2 Preparation for an Orderly Transition to a GPS-Determined Reference Framework

From the discussion in 3 above, it appears that the immediate advantage to adopting GPS will accrue to LRIS from the savings in maintenance and densification of the control network. It also appears that there will not be any significant incentive for users to switch to GPS until conversion to a GPS reference system is virtually completed. Thus it is **recommended** that:

(ii) LRIS adopt a plan by which a GPS-determined reference framework can be implemented with minimum delay.

A first draft of such a plan follows. It is implicit that this plan will be modified many times as new developments occur and as LRIS staff gain experience with GPS technology.

DRAFT FIVE-YEAR PLAN:

1986:

See 4.1 above

Objective: **Familiarization with the technology and verification of the main conclusions in the report.**

1987:

LRIS to lease, or possibly purchase, two GPS receivers and to use them in positioning some control stations and some property surveys in regions where conventional control is not available or where it is unusually costly.

Objective: **Operational experience particularly in establishing "scale factors" relating the ATS77 coordinates to GPS coordinates.**

1988:

LRIS to purchase a pair of receivers (if not purchased in previous year) and start a pilot project in a region where conventional control is due for maintenance; start developing the "scale conversion factors" for the region and encourage the private sector to try using the equipment.

Objective: **Prototype for region-by-region conversion to GPS framework. Orientation for the private sector.**

1989:

Evaluation and further development of the pilot project.

Objective: **An operational plan for conversion from ATS77 to GPS reference framework.**

1990:

If the full constellation of satellites is in orbit, and

if the cost of receivers and data processing facilities has come down as anticipated, and

if the projects outlined above have confirmed the validity of implementing GPS, then proceed with the transition.

4.3 Management of the Existing Control Network

There are three options:

(a) Continue as if nothing was going to change.

(b) Stop all maintenance and densification.

(c) Adopt some intermediate plan.

At this point, we could "on the one hand" and "on the other hand" indefinitely. However, it is our considered opinion that the satellites will be in orbit without significant delays and that the industry will be marketing relatively low cost units as soon as or very soon after the full constellation of satellites is in orbit.

Thus, going on the assumption that the technology will be available, we address the question of how long the land surveyors will need the present networks, i.e., if the new technology does arrive how quickly will they accept it. The answer to this depends on the cost factor and on the alternatives open to them. Weighing all factors, we **conclude** that:

Maintenance and densification of the ATS77 network must be continued until GPS is fully operational and then reviewed again.

However, we **recommend** that:

(iii) Maintenance and densification be done on an "as required" basis rather than on a cyclical basis.

5. SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Findings:

(i) GPS is the only new technology that is both sufficiently promising and sufficiently advanced to warrant investigation in considerable detail at this time.

(ii) Advantages over conventional methods:

(a) The surveyor can determine precise coordinates for any point without having to find and occupy any nearby control stations.

(b) LRIS does not have to maintain a dense network of control stations.

Conclusions:

(i) GPS technology is going to be available much sooner and to have far more impact than was envisioned as recently as one year ago.

(ii) The advantages of GPS technology can only be realized if a new, sparse, but very precise reference network is established and "local scale factors" maintained by LRIS are available for converting all ATS77 coordinates to the GPS coordinate system.

(iii) The maintenance and densification program must be continued in a modified form until GPS is fully operational and then reviewed again.

Recommendations:

(i) A program to familiarize LRIS staff with GPS technology and its implications should be initiated as soon as possible. Specifically, LRIS should second some people to collaborate with UNB's research group on an evalution project that is scheduled for July 1986.

(ii) LRIS should adopt a five year plan for the implementation of GPS.

(iii) Maintenance and densification be done on an “as required” basis rather than on a cyclical basis.

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APPENDIX I

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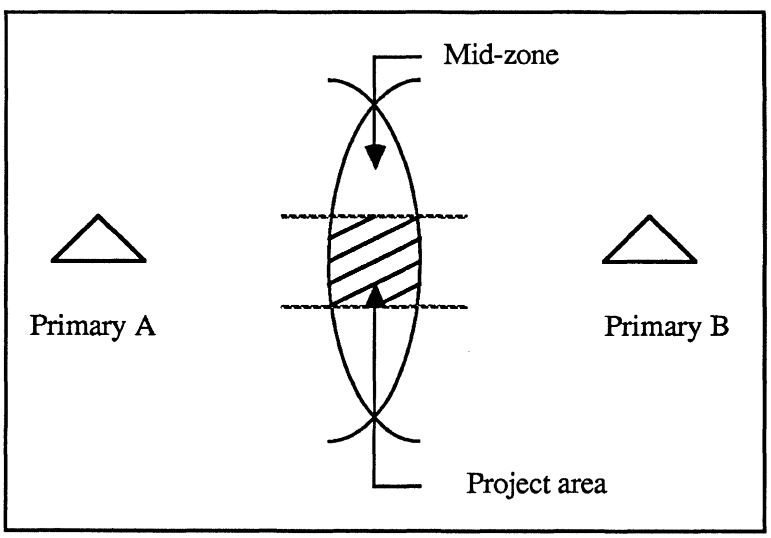
APPENDIX I

SPECIFICATIONS FOR THE ACCURACY AND SPACING OF THE PRIMARY STATIONS

The accuracy specifications are based on a maximum allowable discrepancy between coordinates of the same point **P** determined by two independent surveys referred to two different reference points of the **primary** network.

In deriving the specifications, the following assumption has been made concerning the use of GPS: The positioning of a new station (in the project area) will be always tied to the **nearest** primary station. In this case, the dangerous zones will be created only at "mid-zones" as shown below, where surveys from the different "nearest" primary points may meet together. This means that the worst situations will occur only at mid-distances between the primary stations.



If relative accuracy of the primary network is a/s, where a is the major semi-axis of the 95% relative error ellipse over the distance s, then the maximum expected difference dl between the positionings of the same point will be approximately:

$$dl = \sqrt{a^2 + c_1^2 + c_2^2}$$

where c_1 and c_2 are 95% positioning errors of the two surveys at distances ~ s/2.

Example:

If the relative accuracy of the primary network is $10^{-6} = a/s$ and relative accuracy of the positioning surveys is $10^{-6} = c/s$, then, for a distance s = 50 km,

$$a = 50 \text{ mm}, c_1 = c_2 = 25 \text{ mm}$$

and the expected maximum difference between two positionings would be:

$$dl = \sqrt{50^2 + 25^2 + 25^2} = 61 \text{ mm.}$$

If in the above example $a/s = 10^{-7}$ and $c/s = 10^{-6}$, then:

$$dl = \sqrt{5^2 + 25^2 + 25^2} = 36 \text{ mm.}$$

One can assume (see section 2) that by 1990 the positioning accuracy of the primary network could be in the order of 10^{-7} while the less expensive receivers (possessed by the individual surveyors) will probably give the accuracy of 10^{-6}. Since for most practical purposes the 5 cm accuracy in terms of the expected differences of two positionings seems to be quite sufficient, the spacing of the primary stations should be equal or smaller than 70 km because then

$$dl = \sqrt{7^2 + 35^2 + 35^2} = 50 \text{ mm.}$$

The above calculations are only approximate estimations without a specific confidence level attached to the "accuracy," though the value of 95% probability has been mentioned. The final calculation of the allowable maximum spacing between the primary stations will depend on whether the expected 10^{-6} accuracy of GPS will be at the 1σ or at the 95% level.

Anyway, the spacing will have to be somewhere between 40 km to 70 km, depending on the interpretation of the achievable accuracy of GPS.

APPENDIX II

TRANSCRIPT

of a seminar/workshop held in the LRIS Boardroom
21 October 1985

This seminar/workshop was part of a
CONTROL SURVEY STUDY
done for the

Land Registration and Information Service

by

THE DEPARTMENT OF SURVEYING ENGINEERING
UNIVERSITY OF NEW BRUNSWICK

In August, 1985, LRIS asked the Department of Surveying Engineering, UNB, to review and critique the experience with control surveys to date and, taking into account up-coming positioning techniques, to prepare a scenario for control surveys in the Maritimes in the long term. This meeting was one of the first steps in that study.

At this meeting, LRIS staff members presented statistics on the present maintenance and densification program and members of the Department of Surveying Engineering presented developments and trends in positioning technology and responded to questions.

The objective of this meeting was to draw out as much as possible of the material relevant to the study. Drawing conclusions and formulating recommendations was specifically deferred to a subsequent meeting.

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APPENDIX II

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LRIS-UNB CONTROL SURVEY STUDY
SEMINAR-WORKSHOP
LRIS BOARDROOM
21 October 1985

LRIS Attendees
Bill Robertson
Earl Robinson
Mary Ogilvie
George Schurman
Allen Flemming
Murray Banks
Carl MacDonald
Lewis Carr

UNB Attendees
Adam Chrzanowski
Wolfgang Faig (for Petr Vanícek)
Dave Wells
Richard B. Langley
John McLaughlin
Angus Hamilton

Earl Robinson: Good morning, I am going to be co-chairman this morning so I'll begin by thanking everyone for coming. I see on our agenda which Angus made up there will be some time for Bill Robertson and myself to talk about what our project is and how it affects control surveys. Bill has been away so I don't know how many notes he has, but I'll begin by making a couple of comments, then going over to Bill. Bill is in charge of our control surveys section and he is much more knowledgeable about control surveys than I am. However, we can begin with why and what is this project. I can't think of a better place to begin. A few months ago our Board of Directors had some concerns about the money being thrown into control surveys, in particular, since they had heard about GPS coming and new technology. The Board suggested that we come up with our positions and what way we should be going in control surveys over the next 10 years. So I guess it is safe to say that UNB has the best people to supply advice on GPS. So we went to Prof. Hamilton and ended up finding a time compatible with UNB to carry out the project. The project is is divided into 2 parts: Part 1 is a workshop and a report which will advise us on what may happen to help us in the field of new technology. Part 2 is an evaluation of our present system, which will be carried out during the winter months, and Saint John City because it is an integrated survey area and will be used as a test area.

In both cases, a final report will be produced by the end of March 1986. Now some general information about our control surveys. At the present time we have approximately 50,000 survey monuments. Probably about 20% of those have been destroyed or rendered unusable for some reason, so we really probably have around 40,000 usable monuments. Based on history, we have about 2% of those monuments destroyed every year and we require about 1% for densification. So we require something around 1500 monuments a year. Our contracting budget for control surveys over the last little while has been around $250,000 a year. That does not include in-house people. We also have a considerable in-house budget for control surveys. We have Bill's Control Survey Section in Summerside, and we also have people in each regional office. Our cost per monument at the present time is something around $516 per monument. Now I will turn you over to someone who is really knowledgeable—Bill Robertson.

Bill Robertson: Thank you Earl. I have three points I would like to talk about based on what Earl sent me. He talked about the concerns of the LRIS Board of Directors, so I would like to start this off by talking about some of the concerns we have in Control Surveys.

I'll apologize to you Murray, because these concerns are the same ones we had when I talked to your group in Nova Scotia. Some of the concerns have already been acted on.

We have a maintenance program which we carry on now. I'll talk about the maintenance program procedure we use now, what is involved, and then try to look at some costs, which are a bit difficult to get a grip on.

These are our concerns in the Control Survey Section, the things that are really bothering us at this point, aside from money. Money is a problem, particularly when you look at the physical maintenance. If we assume that we are going to maintain the network, we have to have money to do it.

What we mean by the physical maintenance is the inspection program being carried out on a regular basis and the monuments being replaced as they should be. One of our main concerns was that we were not carrying out any kind of inspection program in the western part of Nova Scotia. There were 2 regions in the western part of N.S. with no activity planned. This year we managed to have a maintenance program in one of them. When I talk about physical maintenance I am assuming that we are going to continue maintaining the network under its present characteristics, which may or may not be a correct assumption.

The second point is the mathematical maintenance of the network. I think most people are aware that in the Maritimes we have been dealing with the original 1927 network. We have had some approximations or local adjustments to the 1927 network. N.B. maintained the original 1927 network; P.E.I. and N.S. did local adjustments to the 1927 network. I am talking about the first-order network now. Following that we had the redefinition to the ATS 77 datum and we produced the error information for all monuments and published that in 1979. Since 1979 we have been continuing to maintain the network to some extent in the physical sense but the question is if it has been maintained in the mathematical sense. What we are doing is holding fixed the points that were established in 1979 and not properly propagating the accuracy information into the new stations. We definitely recognize that we are doing something wrong there and the question is how are we going to improve.

The '83 datum is the third thing that concerns us. The direction we are getting at this point is that we will maintain ATS 77 in the Maritimes. I am not really comfortable with that because, when the '83 datum is finally accepted, the rest of the country will be on the '83 datum and we're going to have the Maritimes sitting down here by itself on the '77 datum.

The next concern is the quality of the vertical control. We in control surveys often questioned if we have any authority in the area of vertical control. We have, sort of, taken it on as a responsibility, as nobody else was doing it. But, really do we have any authority to be in that area. We're certainly not spending any amount of money in that area. The vertical that we do is to provide elevation for the monuments which are necessary to do our job.

Following that is what is going to happen in the Maritimes with NAVD when completed in 1988?

Another concern is what the user expectations are for the coordinate surveying network. Are they expecting too much of us? Much of the original placement of the monuments was done using geodimeters 6 and 6A; there are distances on short lines where Tellurometers were used. Now every surveyor when he does his job is using short range EDM to measure more accurately certainly than much of the equipment that was used to place the network. What are the expectations in that regard? Are we achieving them; can we achieve them?

How the users are using the system is an educational concern. Do they actually know how to use the coordinate system? There is a wide variety of surveyors out there that are making use of the coordinate systems and using them in a variety of different ways.

Another problem we are facing right now is global positioning and what effect that is going to have on the coordinate systems. Will we have an in-house GPS system? Is every surveyor in the next 5 years going to have his own GPS system to work with and not really need the coordinate systems?

Another concern would be the products we provide to our users. Are we giving them enough information? We have people who are working with provincial coordinate systems and people working with geographical coordinate systems and people working in different datums. Are we providing the users with the products they need?

What is going to happen with guaranteed boundaries? Is our network as it is now suitable for a guaranteed boundary system and is the guaranteed boundary system going to come into place?

Our last concern, the last on that list anyway, is offshore positioning. What is the relationship between control surveying and offshore positioning? Those are some of the concerns from people who are actually working in control surveys.

I don't know how we are going to work this next bit. I have been talking away. Do we want people to come back and ask questions at any point?

Earl Robinson: Yes, keep this very informal. Any questions?

Dave Wells: Are you getting any feedback from your users about such things as expectations and do they find that there are discrepancies between what they measure with what they find? What feeling do you get from the users or do you get any feedback?

Bill Robertson: We get a variety of feedback. One rather interesting one came in a couple of weeks ago. Someone was closing between two points and was very concerned that their misclosure was over 5 cm. It's nice to get that concern because he has only run into that problem once and has been using the network for some 15-20 years and that is the only time he has had a misclosure of 5 cm. In his case maybe it is, because he has questioned it. He was really concerned with 5 cm. There are other cases where people will measure distances between monuments and find a definite problem.

Adam Chrzanowski: Do you supply information to the users about the relative accuracies in your network so they won't be concerned about 5 cm?

Bill Robinson: Well that's the question of user expectations and education. There is variance covariance information provided on any point and I would say only 5% of the users even look at it or know that it is on the form. That is probably a high percentage.

Adam Chrzanowski: Some time ago our department made a study for the cadastral accuracy requirements. We came up with a proposal for the designated area of Saint John that the area would be divided into zones of more or less uniform accuracy based on the variance covariance information. For example, in one zone we can get closures of 10 cm, in another zone 5 cm; thus instead of the surveyor having to calculate the relative accuracies he would have this information in a very easy to digest form. It would be the task of LRIS to prepare the zoning and then to give this as kind of specifications to the surveyors. I don't know whether anything in this direction has been done, or if there has been any thinking about it at all. Does LRIS coach the surveyors in using this information?

Bill Robinson: No.

Adam Chrzanowski: So it is up to the surveyors individually to use this information or just look at it.

Mary Ogilvie: George, is Bill's experience the same as yours?

George Schurman: The users expect more of the system than we are able to give them. They expect more than what the relative error ellipses or error ellipses will allow. There hasn't been anything done about zoning in the Saint John area or anything of that.

Adam Chrzanowski: Well, I can see that there is a little disappointment possible if this type of information is rather hidden in the variances and covariances. If someone doesn't know exactly the meaning of this information then they are still disappointed by having a misclosure which in their opinion is too large. Practically, this is all that we can offer.

Bill Robertson: I hope I didn't imply that I think the accuracy of our network is better than 5 cm or 10 cm. I was simply surprised that this was the first time this individual had questioned it.

Lewis Carr: From the user point of view, I think the surveyors, when working on a particular job, who find a misclosure realize that there is no quick fix. In other words, whatever the error is, it is going to show up on the final plan. They obviously can't wait for LRIS to make a major adjustment to get rid of this error. They have to decide, in the working mode, what they are going to do. Make the adjustment and carry on. Perhaps the fact that you are not getting a lot of input may be partially because they know you can't do anything about it at the time, so they carry on. I know from our Branch that we have sent in a lot of information, which went to various offices here in the province, but we realize we are not going to get an answer in time to help us. Smaller errors, such as 5 cm, is the kind of error that people will just look the other way and carry on, because they know we aren't going to be able to call them back in 5 minutes and say, look we have your answer. It just is not going to happen. As a user we find that the information provided us is of a quality we can live with. Obviously, there are places where the errors are going to be seen. When we hit one of those we come up against some problems. We're talking the kind of error that creeps in that will give us headaches, but we realize that if we put a reference line and values in and carry on somewhere an adjustment down the road may take care of it.

Angus Hamilton: You are accepting the monuments and just spreading the discrepancy within the observations that has been made. Is that it?

Lewis Carr: That's generally what we are geared for.

Angus Hamilton: The point is that you are not creating new coordinates or anything like that. You are accepting the framework as such.

Lewis Carr: If we got into that it is so monumental that we could never get out of it.

Angus Hamilton: I agree, but I just want to make it completely clear.

Earl Robinson: Maybe we should move on.

Bill Robertson: I was talking about the maintenance program as it presently exists. The objectives we have for the system is to inspect every monument that is out there once in a 5 year period. The Maritimes are split up into 11 different regions, so really our objective is to inspect 1/5 of each region each year. Having completed the inspection we then know which monuments have been destroyed, and we can select which monuments we feel should be replaced. At the same time as the inspection program, densification would also be carried out. The three objectives are: to inspect the monuments on a 5 year basis; replace those that need it; and densify at the same time.

Dave Wells: How do you decide whether it is required to replace a destroyed monument?

Bill Robertson: Sometimes I guess the decision is pulled out of the air. We wouldn't replace monuments if the location of the monument was such that it wasn't vital to replace it. The first time through you sometimes place monuments on the top of high slopes or along the road, that obviously are going to move, and when those ones are destroyed we are grateful and don't go back and replace them. Basically, the criterion is to try to maintain chains of reasonable spaces of monuments. We try not to have one monument sitting out there by itself.

Dave Wells: What is a reasonable spacing?

Bill Robertson: Well a reasonable spacing in the specifications is 1 kilometre in the outlying area and then down to 300 metres. Sometimes it has come down to taking a look at the map and seeing if the spacing is adequate. It is always a question of adequacy.

The maintenance program: the different phases. The first is what we call the initial inspection. We have the old sketches and in some cases the monument was inspected 5 years ago, but there are still cases where it has been 10 to 15 years since the monument was placed. We have whatever existing sketches are available, we have the monument plotted on the map, and a metal detector and those are the things used in the original inspection in order to find the monument. This is where a lot of your students from UNB get summer work. I think you have probably read enough reports of how the inspection program is carried out to know what's happening.

The next thing is something that began about 4 years ago; it is a layout inspection. After the initial inspection, we know the monument is either there, recovered intact, or has been found destroyed (where evidence of the monument has been found), or else it is still questionable. We haven't found any evidence but we haven't found the monument. In the layout inspection, it is those questionable ones that are cleared up. Starting from the monuments already found, we traverse to the location that the "misplaced" monument was supposed to have been in. At that point we either find the monument, or we find evidence that the monument was destroyed, or we declare it destroyed. After the layout inspection, we now know which monuments have been found destroyed and which ones are declared destroyed. Our next step then is to do reconnaissance. As I mentioned before, it is selective replacement of monuments: we replace only those we feel should be replaced and carry out our densification program at the same time. The first time in the area, there are roads that really should be done but if we can't get normal spacing, the road isn't done. Maybe in 5 years' time the Department of Highways has been in there and straightened the road. That would be considered densification although there were never any monuments placed in that area before. Densification would also occur in town areas where development has occurred. There is sometimes a little difficulty in defining densification or maintenance.

The next step is the construction process. At the present time, the standard monument that we use is the concrete monument with a brass plug on top. Right now we are looking for the right way to go. Are there other monuments that are less expensive but still suitable? One of the obvious ones is the helix monument, but our standard monument right now is the concrete one.

The next stage is the survey itself. The survey is carried out using routine survey methods with specified numbers of angles and distances. The work is normally carried out either by contract or, where we have regional offices, with the survey people in the regional office. As the survey is done, everything is put on a computer coded form and the forms are sent through a regional office to Summerside where the computations are carried out and the values are published and made available to the users. That is maintenance.

Dave Wells: Is there any way of breaking the $500 or $600 down into some of the components.

Bill Robertson: It is not easy, as you can see from three different situations (Tables I, II, III). These three different situations are PEI, NS, and one area in NB from our 1984 program. These are actual costs. If we look at the inspection program itself, inspection is usually done with in-house staff so we have salaries, expenses, vehicle contract costs, and so on and the two different parts of inspection are initial and layout. The overall figure finally when you come down to unit cost, in this particular area in this particular year in these particular circumstances, it cost us about $40 a monument to do the inspection. The reconnaissance costs—again I emphasize this particular situation in this particular region in this particular year as every one varies so much. It depends on how long it has been since the monuments have been placed, and what the quality of the sketches are has a direct effect on how many monuments you find initially and how many you have to lay out. Reconnaissance costs, in this case, came out to be $85. Construction costs based on new monuments of $146 and the survey cost down at the bottom was $152. Now, if you add that all up you are not going to come to $500 a monument, but you don't have your computation cost in there and you don't have your overhead cost. Table II will show a similar sitation in N.S. In this particular situation, the inspection cost was down to $29, the reconnaissance cost the same, about $80, construction was $140 and the survey was $166. Table III will show the situation in Fredericton. In this case the monuments were older. The inspection cost is way up to $65 as it had been longer since the area had been maintained. Thatis $65, $109, $161, $143. So every situation is different.

I have a few more tables here (Tables IV, V, VI, VII) that illustrate that every sitation is indeed different. There in one for each year, but I don't think you want to go into that. Ten different regions and things that have happened the way that the program was done. In Saint John, the figures will be pretty good as I used last year's program. What has been happening so far this year, in Saint John, they inspected 1,017 monuments, recovered 743, the first figure shows 125 were found destroyed initially and then 5, the figure underneath, they were found destroyed by layout and of the 126 they did layout on they recovered 24, found 5 declared destroyed which leaves 76 monuments. The far side, they did reconnaissance of 91 monuments of which none were considered maintenance monuments. In other words, none were replacement monuments, but 91 were densification monuments. Then you go down to the Fredericton region, which is region No. 7, although it is basically considered a similar area. In Fredericton there were 116 monuments put in of which the total 116 monuments were maintenance monuments and no densification monuments. Every area has to be looked at for its own circumstances. It is hard to make generalizations.

Dave Wells: Is it a subjective judgement whether it is maintenance or densification or is it clear?

Bill Robertson: Well, 80% of the time it is clear. We have found tricky ones, where 3 monments have been destroyed and replaced by 2 thus you have a maintenance situation. But if there are 2 monuments destroyed and you replace them with 10, along the same stretch of road, it is densification.

Adam Chrzanowski: What would be the total estimated cost for the program in which every monument would be inspected every 5 years? What would be the estimated total cost, including the average percentage of the destroyed monuments and so on as it is right now.

Bill Robertson: Roughly it is between $50,000 and $80,000 per region.

Adam Chrzanowski: That would be about $250,000 total. It does not include the overhead costs like office and so on.

Wolfgang Faig: No. You are talking about half to 3/4 of a million.

Adam Chrzanowski: How many regions?

TABLE I

Actual Figures From P.E.I. Inspection Program 1984-85

Program: Inspection of 789 monuments including 150 layouts, reconnaissance, construction and survey of 76 new monuments (149 occupied stations for survey).

Inspection	(Initial)	(Layout)	Total		
Salaries	$4,879.50	$6,767.66	$11,647.16	37%	
Travel Expenses	4,021.10	6,093.36	10,114.46	33%	
Vehicles	2,343.66	3,028.09	5,371.75	17%	
Material & Eq.	3,630.81	446.78	4,077.59	13%	
Contract Costs	0.00	0.00	0.00	0%	
	$14,875.07	$16,335.89	$31,210.96	100%	52%

Unit Cost $31,210.96 ÷ 789 = $39.56 (estimate $55)

Reconnaissance			
Salaries	$2,596.23	40%	
Travel Expenses	2,447.90	38%	
Vehicles	1,302.49	20%	
Material & Equipment	150.67	2%	
Contract Costs	0.00	0%	
	$6,497.29	100%	11%

Unit Cost $6,497.29 ÷ 76 = $85.49 (estimate $100)

Construction				
Salaries	$1,167.64		10%	
Travel Expenses	221.60		2%	
Vehicles	336.99		3%	
Material & Equipment	441.62	(with plugs)	4%	
Contract Costs	8,968.00		81%	
	$11,135.85		100%	18%

Unit Cost $11,135.85 ÷ 76 = $146.52 (estimate $145)

Survey		
Contract	$11,569.50	19%
		100%

Unit cost per new station $11,569.50 ÷ 76 = $152.23

Unit cost per occupied station $11,569.50 ÷ 149 = 77.60

Estimate $95.00 per occupied station or $118.75 per new station

TABLE II

Actual Figures from N.S. Regional Offices Inspection Program

Program: Inspection of 4046 monuments including 164 layouts, reconnaissance, construction and survey of 344 new monuments (149 occupied stations for survey).

Inspection

Salaries	$89,740.94	76%	
Travel Expenses	6,269.53	5%	
Vehicles	16,774.84	14%	
Material & Equipment	5,685.04	5%	
Contract Costs	0.00	0%	
	$118,470.35	100%	47%

Unit Cost $118,470.35 + 4046 = $29.28 (estimate $55)

Reconnaissance

Salaries	$21,062.45	74%	
Travel Expenses	3,644.77	13%	
Vehicles	2,435.53	8%	
Material & Equipment	1,401.63	5%	
Contract Costs	0.00	0%	
	$28,545.38	100%	11%

Unit Cost $28,545.38 ÷ 344 = $82.98 (estimate $100)

Construction

Salaries	$ 5,915.96	12%	
Travel Expenses	1,677.99	4%	
Vehicles	586.60	1%	
Material & Equipment	3,331.34	7%	
Contract Costs	36,701.77	76%	
	$48,213.66	100%	19%

Unit Cost $48,213.66 + 344 = $140.16 (estimate $145)

Survey

Salaries	$37,566.66	65%	
Travel Expenses	3,483.34	6%	
Vehicles	2,666.28	5%	
Material & Equipment	13,521.77	24%	
Contract Costs	0.00	0%	
	$57,238.05	100%	23%
			100%

Unit Cost Per <u>New</u> Station $57,238.05 + 344 = $166.39 (estimate $118.75).

TABLE III

Actual Figures From Fredericton Inspection Program 1984-85

Program: Inspection of 697 monuments including 155 layouts, reconnaissance, construction and survey of 116 new monuments (193 occupied stations for survey).

Inspection	(Initial)	(Layout)	Total		
Salaries	$14,772.05	$4,947.98	$19,720.03	43%	
Travel Expenses	8,164.63	3,313.26	11,477.89	25%	
Vehicles	5,231.16	3,237.11	8,468.27	19%	
Material & Eq.	5,253.82	617.88	5,871.70	13%	
Contract Costs	0.00	0.00	0.00	0%	
	$33,421.66	$12,116.23	$45,537.89	100%	49%

Unit Cost $45,537.89 + 697 = $65.33 (estimate $55)

Reconnaissance			
Salaries	$4,801.62	38%	
Travel Expenses	3,580.69	28%	
Vehicles	3,977.31	32%	
Material & Equipment	301.65	2%	
Contract Costs	0.00	C%	
	$12,561 27	100%	13%

Unit Cost $12,661.27 ÷ 116 = $109.15 (estimate $100)

Construction			
Salaries	$1,614.42	9%	
Travel Expenses	696.40	4%	
Vehicles	1,843.41	10%	
Material & Equipment	604.78 (with plugs)	3%	
Contract Costs	14,030.00	74%	
	$18,789.01	100%	20%

Unit Cost $18,789.01 + 116 = $161.97 (estimate $145)

Survey			
Salaries	$2,771.77	17%	
Travel Expenses	157.51	1%	
Vehicles	0.00	0%	
Material & Equipment	29.31	0%	
Contract Costs	13,705.20	82%	
	$16,663.79	100%	18%
			100%

Unit cost per new station $16,663.79 + 116 = $143.65
Unit cost per occupied station $16,663.79 + 193 = 86.34
Estimate $95.00 per occupied station or $118.75 per new station

TABLE IV

MAINTENANCE PROGRAM FOR 1985-86

Region		Year	# Inspected	# Recovered	# Found	Dest./D.D.	Layout	Other	Reconnaissance Maint./Dens.
1) Saint John	NB	85-86	843	498	104	-	207	34	40
Saint John	NB	85-86	-	12	9	73	-	113	-/-
2) PEI	PEI	85-86	871	650	153	-	67	1	69
PEI	PEI	85-86	-	15	9	41	-	2	32/37
3) Moncton	NB	85-86	358	344	12	-	2	-	47
Moncton	NB	85-86	-	11	13	25	49*	-	24/23
4) Halifax	NS	85-86	280	248	31	-	2	-	72
Halifax	NS	85-86	-	0	0	0	2	-	-/-
5) New Glasgow	NS	85-86	196	172	18	-	6	-	88
New Glasgow	NS	85-86	-	0	0	0	-	0	88/0
6) Bathurst	NB	85-86	44	30	5	-	9	-	103
Bathurst	NB	85-86	-	34	39	74	163*	16	67/36
7) Fredericton	NB	85-86	858	634	52	-	156	16	173
Fredericton	NB	85-86	-	33	15	87	-	21	36/137
8) Sydney	NS	85-86	891	816	40	-	34	1	82
Sydney	NS	85-86	-	25	50	7	83*	1	7/75
9) Lawrencetown	NS	85-86	0	-	-	-	-	-	0
10) South Shore	NS	85-86	434	335	50	-	37	12	58
South Shore	NS	85-86	-	11	1	9	-	16	5/53
11) Edmundston	NB	85-86	0	0	0	0	0	0	0

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TABLE V
MAINTENANCE PROGRAM FOR 1984-85

Region		Year	# Inspected	# Recovered	# Found	Dest./D.D.	Layout	Other	Reconnaissance Maint./Dens.
1) Saint John	NB	84-85	1017	743	125	-	126	23	91
Saint John	NB	84-85	-	24	5	76	-	21	0/91
2) PEI	PEI	84-85	789	454	168	-	167	0	76
PEI	PEI	84-85	-	35	36	79	-	17	76/0
3) Moncton	NB	84-85	690	607	52	-	31	-	120
Moncton	NB	84-85	-	7	4	44	55*	-	66/54
4) Halifax	NS	84-85	942	856	57	-	29	-	147
Halifax	NS	84-85	-	9	3	17	-	-	147/0
5) New Glasgow	NS	84-85	1390	1191	105	-	94	-	108
New Glasgow	NS	84-85	-	11	11	49	2	23	17/91
6) Bathurst	NB	84-85	1169	682	220	-	267	-	224
Bathurst	NB	84-85	-	50	33	78	-	106	46/178
7) Fredericton	NB	84-85	697	368	98	-	236	-	116
Fredericton	NB	84-85	?	24	17	112	-	83	116/0
8) Sydney	NS	84-85	2236	1754	101	-	381	-	101
Sydney	NS	84-85	-	57	6	29	-	289	-/-
9) Lawrencetown	NS	84-85	0	-	-	-	-	-	0
10) South Shore	NS	84-85	0	-	-	-	-	-	0
11) Edmundston	NB	84-85	373	306	24	-	43	-	110
Edmundston	NB	84-85	-	11	6	26	-	-	27/83

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TABLE VI

MAINTENANCE PROGRAM FOR 1983-84

Region		Year	# Inspected	# Recovered	# Found	Dest./D.D.	Layout	Other	Reconnaissance Maint./Dens.
1) Saint John	NB	83-84	726	544	89	-	93	-	142
Saint John	NB	83-84	-	6	0	20	26*	-	-/-
2) PEI	PEI	83-84	791	509	27	-	255	-	61
PEI	PEI	83-84	-	80	21	15	116*	-	61/0
3) Moncton	NB	83-84	822	749	49	-	24	-	106
Moncton	NB	83-84	-	21	33	86	140*	-	106/0
4) Halifax	NS	83-84	762	716	46	-	13	-	161
Halifax	NS	83-84	-	6	7	7	-	-	0/161
5) New Glasgow	NS	83-84	924	814	80	-	27	-	135
New Glasgow	NS	83-84	-	7	4	16	-	-	52/83
6) Bathurst	NB	83-84	1254	796	157	-	303	-	243
Bathurst	NB	83-84	-	19	11	33	94*	31	133/110
7) Fredericton	NB	83-84	597	289	112	-	196	-	164
Fredericton	NB	83-84	?	52	38	99	-	-	164/0
8) Sydney	NS	83-84	730	652	41	-	37	-	96
Sydney	NS	83-84	-	-	-	-	-	-	88/8
9) Lawrencetown	NS	83-84	870	766	29	-	94	1	71
Lawrencetown	NS	83-84		29	2	51	-	12	55/16
10) South Shore	NS	83-84	900	782	32	-	86	-	81
South Shore	NS	83-84	-	24	8	40	-	14	59/22
11) Edmundston	NB	83-84	400	246	58	-	96	-	126
Edmundston	NB	83-84	-	34	15	33	-	14	122/4

Doc. 2073e/1985.10.24

TABLE VII

MAINTENANCE PROGRAM FOR 1982-83

Region		Year	# Inspected	# Recovered	# Found	Dest./D.D.	Layout	Other	Reconnaissance Maint./Dens.
1) Saint John	NB	82-83	954	704	113	–	137	–	66
Saint John	NB	82-83	–	24	20	50	94*	–	31/35
2) PEI	PEI	82-83	0	0	0	–	0	–	145
PEI	PEI	82-83	–	93	95	143	331*	–	122/23
3) Moncton	NB	82-83	812	551	60	–	271	–	174
Moncton	NB	82-83	–	17	47	70	134*	–	108/66
4) Halifax	NS	82-83	828	731	34	–	63	–	47
Halifax	NS	82-83	–	0	0	0	0	–	19/28
5) New Glasgow	NS	82-83	1625	1388	118	–	119	–	55
New Glasgow	NS	82-83	–	145	93	132	373*	–	–/–
6) Bathurst	NB	82-83	0	0	0	–	0	–	156
Bathurst	NB	82-83	–	0	0	0	0	–	54/102
7) Fredericton	NB	82-83	0	0	0	–	0	–	0
8) Sydney	NS	82-83	809	724	38	–	46	–	65
Sydney	NS	82-83	–	0	0	0	–	–	7/58
9) Lawrencetown	NS	82-83	400	348	23	–	35	–	19
9) Lawrencetown	NS	82-83		9	4	13	26*	–	19/0
10) South Shore	NS	82-83	817	621	53	–	142	–	126
South Shore	NS	82-83	–	30	5	47	92*	–	59/67
11) Edmundston	NB	82-83	673	408	88	–	177	–	75
Edmundston	NB	82-83	–	50	17	79	164*	–	71/4

Everyone: 11 regions.

Bill Robertson: 11 times $60,000.

Wolfgang Faig: Half to 3/4 of a million.

Bill Robertson: We have had a fairly standard program in P.E.I. for the past 3 or 4 years which is a straight $50,000. I would say that P.E.I. is on line.

Adam Chrzanowski: So this would be per year.

Earl Robinson: Any other questions for Bill? In that case I'll turn you over to the other co-chairman, Angus Hamilton.

Angus Hamilton: Thank you Earl. Thank you Bill. I think that has been very informative for all of us on the UNB side. One of the items I would like to mention is that Dr. Vanícek, who was to be our lead-off speaker, was stricken with gall bladder problems and had an operation on Wednesday night. He is Mr. Geodesy, the senior author of the monumental textbook *Geodesy: The Concepts* , and very much interested and concerned with geodesy *per se*. However, Dr. Faig has been briefed by Dr. Vanícek, and although I'm not sure how he was allowed into the geodesy club, he has some information to relay to you. Also we have handed out the monograph *Geodesy: A Look at the Future*. It is a U.S. publication but if you look inside you will find that Dr. Vanícek is one of the co-authors on the committee that prepared this volume. I believe that he would have been referring to this at times. I don't know just how much of it is relevant to our immediate task, but it is something to take home as tangible evidence that you have got something from the meeting here. You can put it on your coffee table and impress your friends.

I shall just take a minute to refer to the procedures we are proposing. As you can see the meeting is being taped. We propose to get a draft of the discussions and send them around for correction by the authors and then get a version that reflects within reason what we have discussed here.

In the longer term, partly because of Dr. Vanícek's absence and partly because of the range of the subject, we really see this as the first stage of a seminar/workshop series on this question. In other words, today we take a look at the state of the art of the new technology. We have had input from Bill on the control. Later in part 2 of our study we expect to have a draft report on the user situation. Then we will have another session where we try to bring these two together. I anticipate a meeting, hopefully in mid-winter, where we can come to a concensus. Today, we are focusing on the best assessment of what we anticipate the technology can do in the next few years.

Wolfgang Faig: It is totally impossible for me to impersonate Dr. Vanícek, but I have done quite a bit of reading in the last few days, as you can imagine, and I have spent some time with Petr who sends his greetings and apologies for not being able to make it and hopes to be out of the hospital in a few days. Knowing him, he will be back at work shortly thereafter.

Anyway, the area that Petr was supposed to talk about and what he has passed on in his comments plus some of the things I have read, is on long term trends in geodesy, well beyond the 10 years that Earl was talking about. I think even when you make short term decisions you have to look ahead so that these are not done in isolation but in the context of what may happen or can happen. To get back to technological developments, they have always had a significant impact on surveying and I just want to mention a few.

Just to recall: Originally mapping was done by plane-tabling and that was totally replaced by aerial photogrammetry. It was a quantum leap. Similarly, computer technology came into surveying and all of a sudden we were able to do large adjustments and photogrammetry became analytical. EDM has totally changed the approach to surveying. Networks prior to that were done by triangulation; distances were a real pain, and to run a baseline was avoided like the plague. Nowadays, often we do not measure angles but use only distance arc sections and things like that because it has become very easy. Similarly, space techniques are coming into surveying, and my colleagues will talk about that in detail. At the present moment, they are in an early stage of development, but everybody can perceive another revolution in surveying. The pattern has always been the same. New technology, often developed by non-surveyors, leads to new surveying equipment which in turn causes existing procedures to be changed. More frequently, new developments of procedures take place and not just in the same situation as before. This is where the profession comes in. Unless the profession is willing to follow this trend, make use of the new technology, and provide leadership in the field, somebody else will swallow up the profession and carry the ball. This is a real danger and surveyors have often been a little conservative until all of a sudden they wake up and try to scramble back. This is something that will have to be kept in mind. Before I go into the speculations of what could happen in the next century, I would like to address just some basic concerns of surveyors and their relationship with society, which is served by surveyors.

Surveyors, although they sometimes think they do, don't work in isolation but work for some purpose. I would like to restrict myself here to land surveyors, not necessarily in the legal sense but I would like to omit areas like hydrographic surveys which are not of much interest to LRIS, although Bill mentioned offshore surveys tying in.

(about 6 minutes of tape missing)

So if I were to repeat this again, he foresees three-dimensional absolute quasi-instantaneous positioning capability accuracy of 1 cm being relatively cheap and portable. This is not really as far fetched as it sounds, because we have already absolute positioning capability, and the monograph that Angus mentioned quotes 2 cm now and 1 cm before the end of this century. Satellite laser ranging provides a relative accuracy at the moment of 1.6 x 10^{-9} so you have this capability already. VLBI, which is a purely relative positioning device over huge distances, gives you a similar accuracy. I'm sure that Richard can give you more details. The absolute positions on GPS are about 1 metre, however, the relative accuracy is about 2 x 10^{-7}, which once again is in the centimetre range when you talk relative positioning. What the real drawback is, and everybody will be working on this within the next year or decade, is that you have large and expensive hardware combined with time consuming procedures. This is why it hasn't made much impact yet on the profession. Satellite laser ranging takes about three months to get this result. VLBI requires several sessions of several days each to obtain this accuracy. GPS takes at least 5 hours to get this 1 metre accuracy. There is some instantaneous GPS reaching about 5 metre accuracy. At the moment, relative GPS in the simultaneous mode has, according to Petr, not been domesticated yet. It is possible. So research will go primarily into decreasing the observation time as well as the hardware size and cost. There will likely be an international effort to bring these down and once this is achieved, then we can get to there. So if this thesis 1 becomes reality by the turn of the century, there is no longer a need for closeby positions as provided by geodetic networks. Relative positioning over thousands of kilometres, or absolute positioning will be available within the required accuracy. This leads to thesis No. 2.

A network of monitoring stations will be established in Canada—apparently the Geodetic Survey of Canada is thinking along this line. This is followed up by thesis No. 3, which says that within a one hundred year scenario the trend to miniaturization and cost reduction postulated in thesis No. 1 will lead to the evolution of the cheap wrist locator, like a wrist watch, giving instantaneous position to millimetre accuracy. With the coming of the position oriented society, this instrumentation should be cheap, $10, because it is a consequence of a mass market. There are already indications of this trend. Within about 10 years from now they expect to have small satellite positioning devices in automobiles. So you get instantaneous positioning of your car.

Let us now have a look at this network of monitoring stations because it is conceivable that at least part of the present control network, perhaps with some readjustment and remeasurement, could be used as a monitoring network. That will play a key role in the transition into what we call the position oriented society. Obviously, other countries will establish monitoring points and it remains to be seen whether Canada will be leading the way and keep its leading edge or give way to someone else. What are these monitoring points for? Well, in addition to some geodynamic phenomena, I'll mention those a little bit later, there are four major areas of service, some of which could quite likely become part of LRIS's role in a position oriented society. It is necessary to keep the public instantaneously informed in the future, and changes in the data base are fed into the monitor. The land information managers will have a key role to play in this area.

There are four areas of service as Petr envisaged and they are: high-accuracy geodetic positioning and this is basically a fixed-in service and is equivalent to what is done now but it is immediate and continuous. He talks here about relative positioning by using something like GPS or GLONASS which is the Russian equivalent of GPS, perhaps slightly better, and others plus optical position evaluation. So the monitoring network then provides a framework of relative positioning rather than higher-accuracy; then absolute positioning can go. There will always be a somewhat lower accuracy.

Secondly, for high accuracy positioning, we also have that for differential navigation, once again a relative approach. The second one would be orbit improvement, which would be a continuous service. This is something that exceeds LRIS's role because in order to do this and the orbit improvement which in turn will improve the absolute positioning capabilities, this is only viable with monitoring stations that cover say a continent but again LRIS could provide a part of those stations.

Number three would be mapping and charting. This is an immediate service extracting the information from continuously updated data bases and matching them with positioning. He is not talking here about conventional maps, but he talks of examples like road maps with updated instantaneous capabilities that would show construction areas, detours, snow and ice conditions, blockages, traffic holdups, etc., instantaneous data metric maps, tourist maps that provide information on what attractions are open, what is recommended at sites superimposed onto positions. For any other thematic maps, aeronautical charts, you have a continuous update of map information.

Four would be tracking and dispatching. Here you have instantaneous service gathering information and selectively distributing it. Examples here are: the location of something like taxi fleets, fire trucks, ambulances, police cruisers, tractor trailers, any other transportation units, car rental operations, etc. This would require cheap land navigation positioning devices in the mobile units which are then monitored via the monitoring stations and have instantaneous distribution.

All of this sounds rather futuristic and does not necessarily follow within the area of LRIS but let us now come back to the geodynamic aspects and perhaps LRIS's main contribution will lie in this area.

Three aspects come to mind in conjunction with monitoring points. One would be the modelling and with it the prediction of the geodynamic aspects. As I mentioned earlier, we didn't need those before but all of a sudden we have spatial reference and we have to monitor changes in time. Mathematical models as functions of the modelling points are already available and the knowledge is then needed to transform these absolute three-dimensional positions that we have into something that is user friendly. The user really will not be familiar with the concept of an extra-terrestrial coordinate system. So he wants his maps where the contours would be still parallel to mean sea level or something like this. It is necessary to provide mathematical models and transforms and predict perhaps some of those known parameters over long period changes in the earth's position, so that we can transform this absolute coordinate knowledge into something that is useful for the user, as I said, so that the map still has contours and charts sea level elevations and things of that nature. Because that is what we have to provide.

The second item is the maintenance of geodynamic point arrays in the areas of interest. When I talked about point arrays earlier, I mentioned that these are points which carry position plus other information. We discussed this and came up with three areas which would be of primary interest. One would be the Miramichi earthquake epicentre. There we have geodynamic movements and the monitoring of these movements, which means then that the monuments there would perhaps be converted into monitoring stations. The concept changes and this coordinate change gives information on what is happening in this tectonic area. Secondly there is a tectonic movement region near St. Stephen. Apparently U.S. experts have discovered a point of rapid subsidence. Perhaps thirdly this should be extended along the Bay of Fundy coast. Some of these tectonic changes could change the resulting changes to the U.S./Canada boundary for instance. Of course there is also tectonic activity in the area of Pt. Lepreau which is rather sensitive, especially politically. So looking at this from the political point of view, it may be desirable for LRIS to have this type of information. Since that is desirable, it also may be politically attractive and therefore worthwhile for government funding.

Thirdly, look for new areas and phenomena that needed to be monitored. One of the items that comes to mind is subsidence monitoring in mining areas and settlement areas. The potash mining that is taking place in N.B. now will eventually lead to this type of thing. The same applies to coal mining in N.S. I know there is subsidence, especially extending from Cape Breton below the sea floor and things of that nature.

So all these tasks require positioning experts, and really things of this sort are more or less of a regional stature. It goes clearly beyond the client/surveyor relationship. Not one single client and not one single surveyor is interested in some of these things to the extent of actually doing them. It would be ideal if an organization like LRIS would act and, of course, I haven't even mentioned that in the long run we will need an instantaneous reponse to all property related matters.

So this is roughly an outlook as we perceive it: what **could** happen. It could happen much faster but we don't know just how fast technology will change. These types of things have to be kept in mind even when looking at the short run—your geodetic networks.

Angus Hamilton: Thank you very much.

Adam Chrzanowski: I introduced myself earlier as being one of the members of the UNB gang. According to the program, I would like to give a view of the present technologies, which are available in surveying, and to give a brief introduction to the different technologies which later on will be discussed separately by different speakers.

Here is the famous bubble chart (Figure 1) which we have used in many publications, co-authored by several members of our department, when talking about the comparison of different technologies, particularly when comparing the different technologies with GPS (see Figure 1A for a slightly different presentation of this information). At the time when we wrote the first paper including this bubble chart, GPS was really the future technology—just coming. Right now we already have GPS working, not fully, but already achieving good results. Therefore we will give more attention to GPS during this seminar than to other technologies. Nevertheless, we have to look at all the other technologies because, who knows, there might be some progress in other technologies like the inertial survey systems.

As you could see in our first presentation, inertial survey systems were listed as giving accuracies somewhere between 20 cm in the best case, and 50 cm or even less. So on this bar of the chart we have the accuracies in cm and here distances between stations in a logarithmic scale. We have terrestrial surveys or conventional terrestrial surveys, with measurements of EDM distances, where the accuracies as we know can range from a few millimetres in special types of surveys to 20 cm in distances from a few tens of metres to several kilometres. When talking about the usefulness for the positioning systems, we have the satellite Doppler system which will probably cease to exist in a few years after the full constellation of the GPS satellites is in place. Inertial surveying systems with typical ranges between say 5 to 100 km, which, as I mentioned, is marked as giving 20 cm accuracy. The very recent developments indicate that we can increase the accuracy to a few cm with the inertial survey system. So, it is a technology which may compete with other technologies in the future. The Global Positioning System, which Dave Wells will talk about later, gives accuracies within a few millimetres over short distances. This area here may be changing. This is what we gave in our first paper, the range of the application as far as distances are concerned.

We have 2 other technologies which we should mention; the satellite laser ranging (see Figure 2), and very long baseline interferometry (see Figure 3) which give extremely high accuracies in the order of 10^{-7} which are mainly used in geodynamic studies and in tectonic movement studies. Nevertheless, with improving technology, when the satellite laser ranging instrumentation becomes more portable, who knows, it may happen that this technology will give us also sufficient accuracy in a comparatively short time to be used in routine positioning surveys. The same with VLBI. When talking about satellite laser ranging, one should mention a new approach now coming with the laser ranging. It is placing the laser on the satellite or generally airborne, with the reflectors placed on the ground and using the so-called airborne laser ranging which may give the accuracy of about 1 cm in a relatively short time—maybe one hour of time. This could be perfect for establishing, for instance, control for photogrammetric mapping.

I have highlighted, however, only these 3 technologies over here because we shall talk more about those three developments when talking about a possible competition between different techniques. As far as the terrestrial surveys are concerned, we don't have too many new developments and I don't foresee really great improvements in the near future. We have to measure angles; we have to measure distances in order to position new points with respect to selected reference networks. We are now facing a progress in automation, computerization of the systems. We have new electronic theodolites like the Kern E2, Wild T2000 which offer accuracies equivalent to the first order theodolites like Kern DKM3 or Wild T3. In a much shorter time, fewer sets of measurements are required because the graduation errors have practically been eliminated in those theodolites. We have full computerization of the data acquisition, on line data processing in the field, but practically, the basic principles stay the same. We have to have intervisibility between the stations, we have to occupy the station from which we want to position a new one or we have to occupy the new station and have visibility to the control stations in order to determine our positions. So here, if any progress would come in the accuracy it wouldn't affect our land surveys because the accuracy presently is sufficient. We are already talking about accuracies of 1 cm per km as an easy achievable accuracy in relative positioning using terrestrial surveys. The time consumption is mainly the logistics of moving between the stations because the measurements become very easy and very fast so it is a question of minutes to get a measured line and the direction between two stations. So here we don't expect too

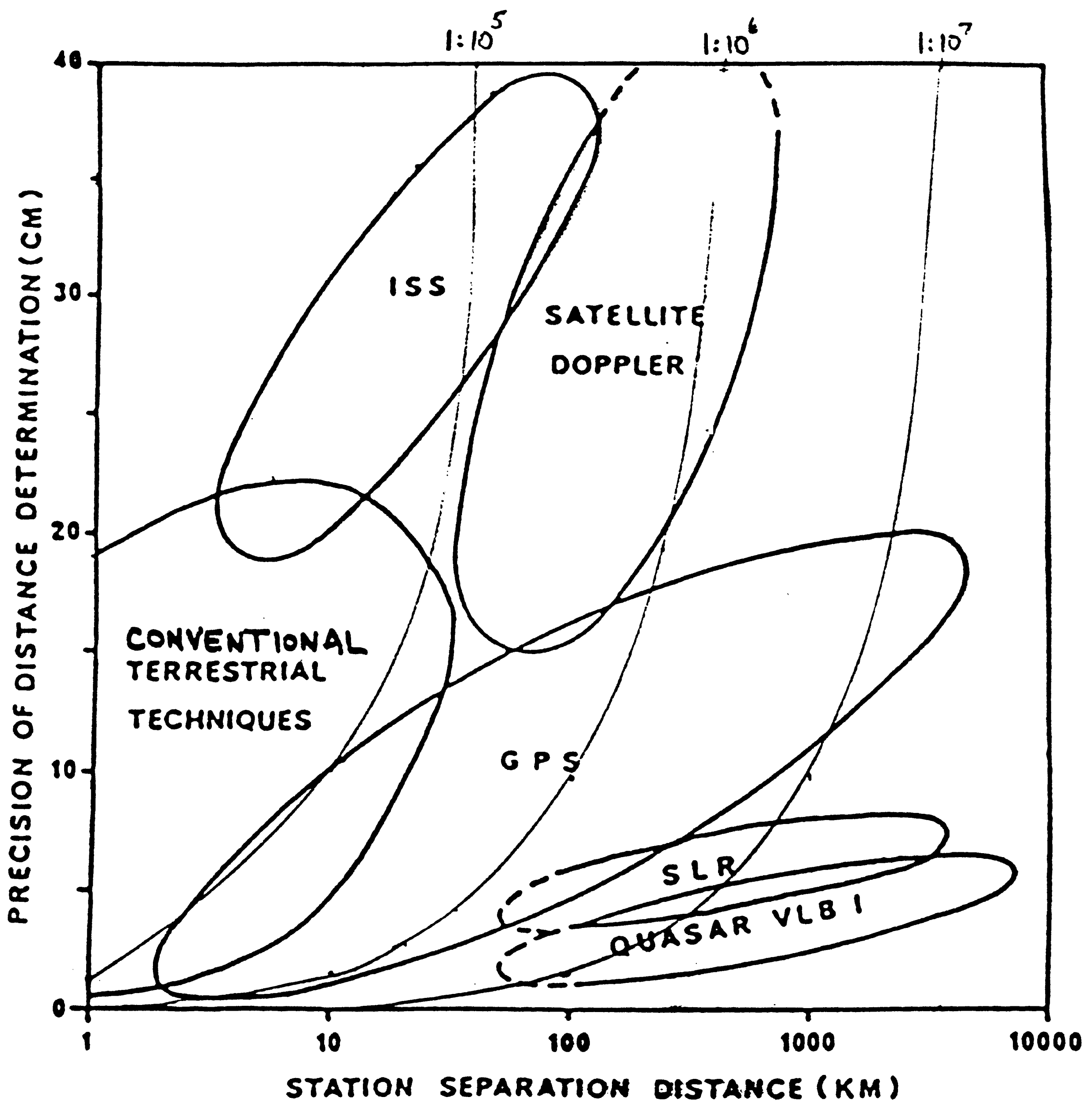


FIGURE 1. PRECISION OF DISTANCE DETERMINATION.

FIGURE 1A

NEW TECHNOLOGIES
ACCURACY VS. DISTANCE

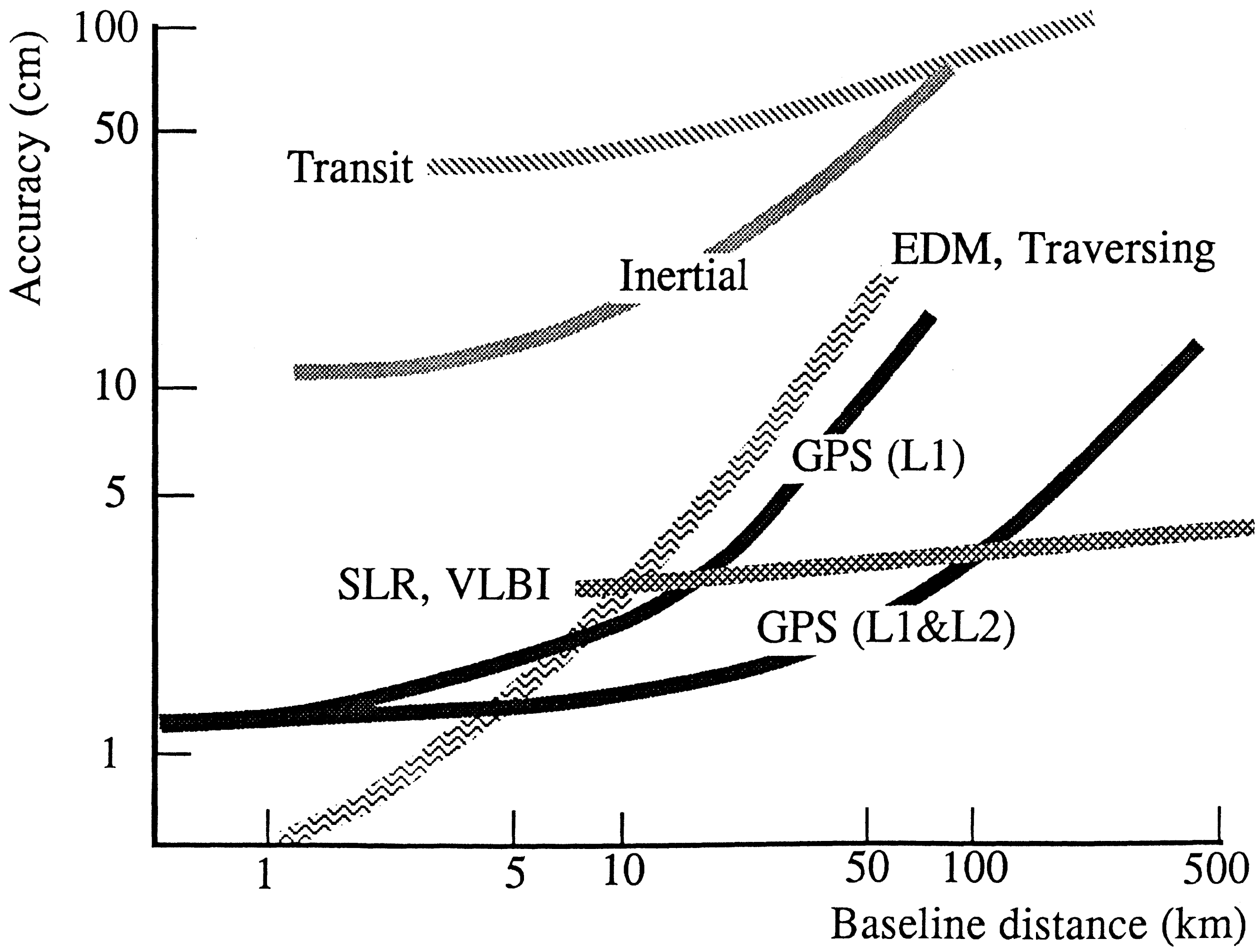


FIGURE 2

SATELLITE LASER RANGING

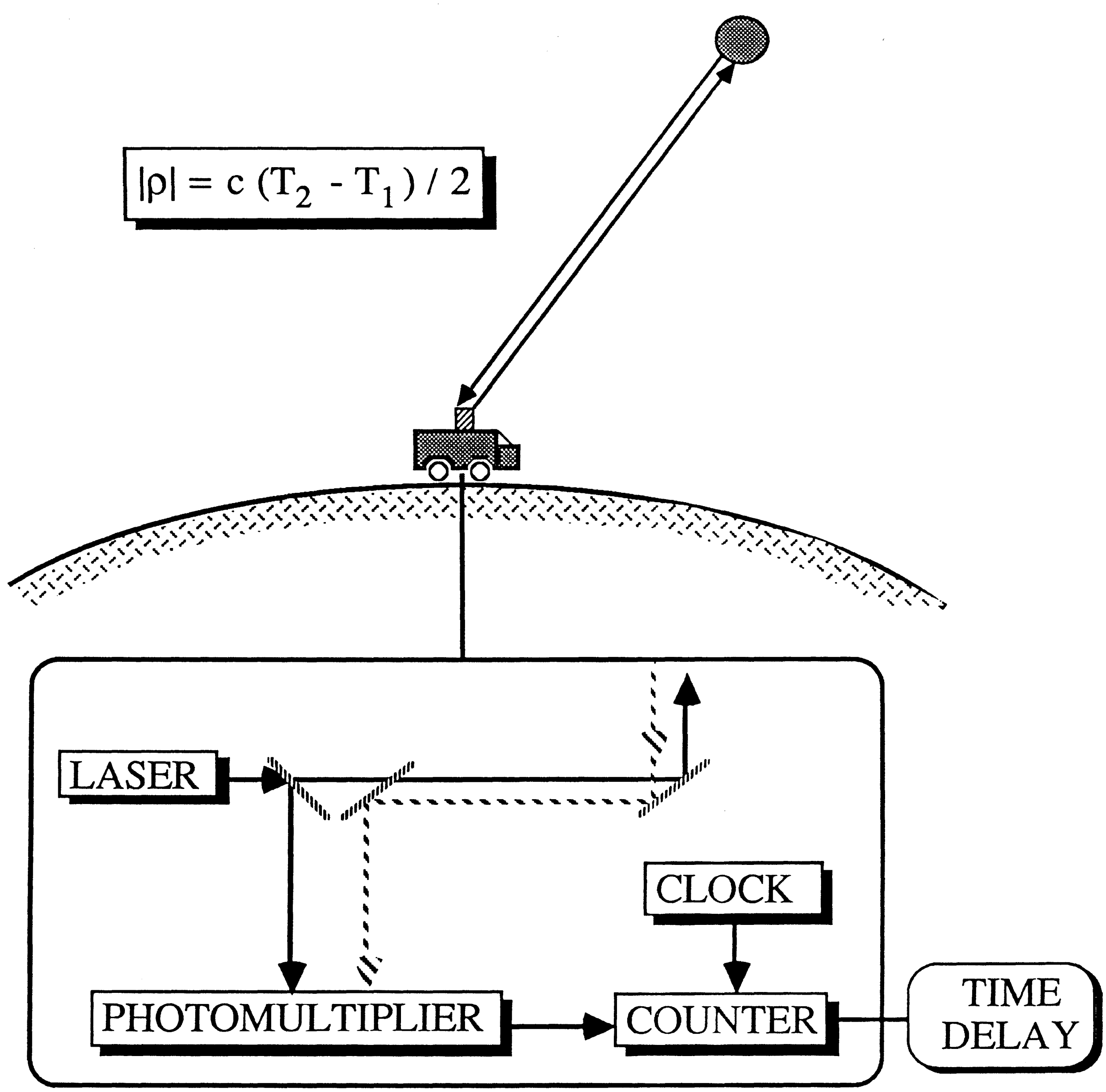
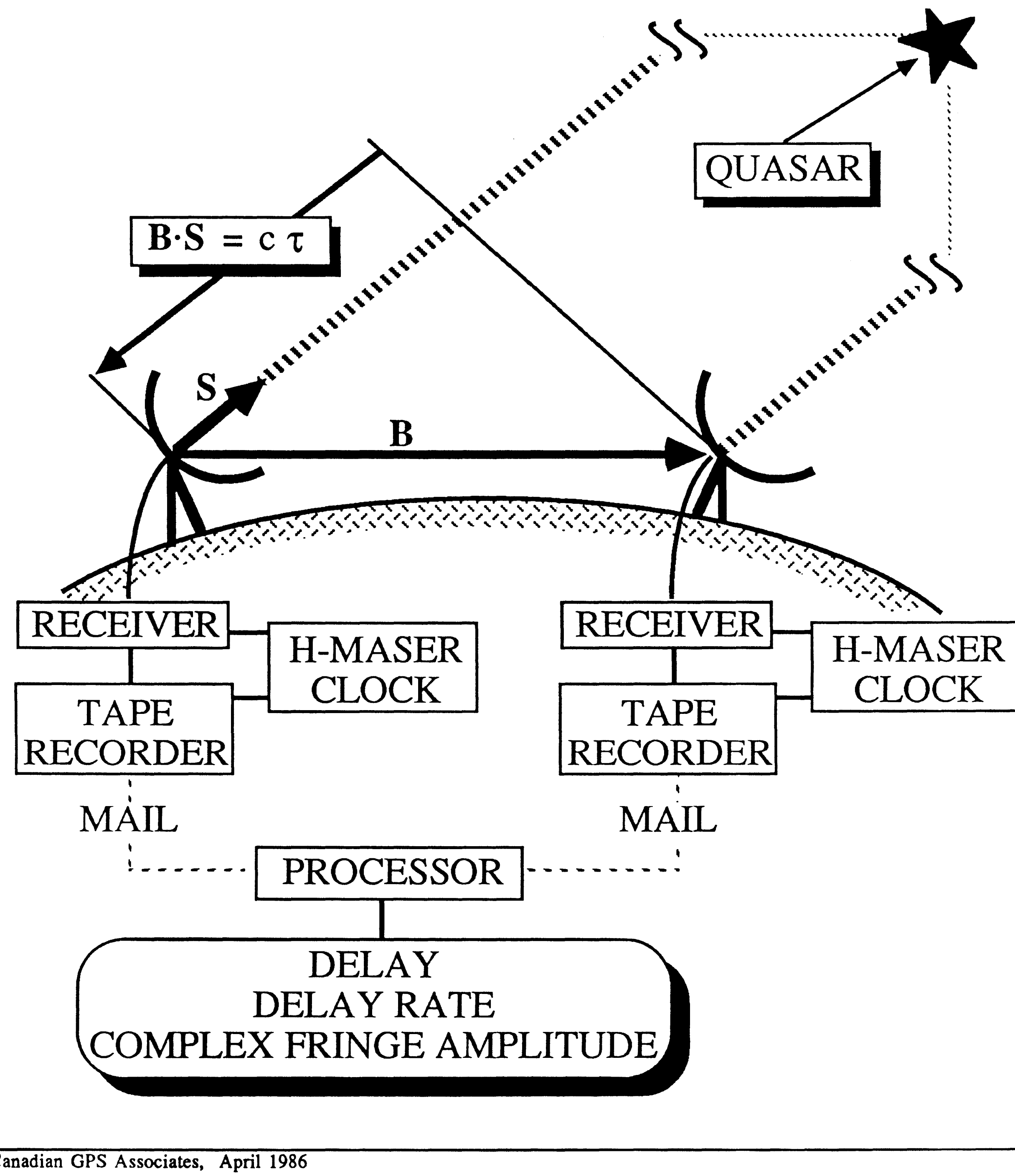


FIGURE 3

VERY LONG BASELINE INTERFEROMETRY



much improvement except of special applications of terrestrial surveys like engineering surveys where higher and higher accuracy requirements are coming, where sub-millimetre accuracies are needed very often.

Then we talk about the possible further improvements in the technology but when talking about the involvement of LRIS, I would not foresee any dramatic changes in the techniques and in the methods of surveys. Still there will be angles, distances, and vertical control levelling. In levelling we have the motorized systems in operation with the speed of up to 15 km in flat terrain using spirit level principles. Very recently, we have gone into the application of the new electronic theodolites in motorized trigonometric height traversing which gives some improvement because we can now get also 15 km speed in hilly areas which, when using the horizontal lines of sight, is limited by the inclination of the terrain and then the speed of normal conventional levelling is sometimes only 2 km per day when talking about mountainous areas. With our technique, which we developed at UNB, we can get 15 km per day independent of the topography of the terrain and without the accumulation of systematic refraction errors, as was proven during the last summer on a test network near Fredericton. But again, it is just a small improvement, nothing dramatic, so we cannot talk about any real impact in the future of the terrestrial techniques on the positioning surveys.

Bill Robertson: On the borderlines, are you saying that you are getting the same accuracy with motorized spirit levelling?

Adam Chrzanowski: Well, we are getting better than 2 mm per km, without influence of systematic errors which is the main problem in spirit levelling.

Bill Robertson: But you are not getting the same with the motorized spirit levelling as you are with the motorized trig levelling, or are you?

Adam Chrzanowski: Well, close to it, yes. Very close. We get accuracies between 1 to 2 mm/km, which is of one-way levelling, which is already better than first-order requirements for closures. About inertial surveys, we shall talk about that a little later on. Then Dave will talk about GPS. Now I would like to ask Richard Langley to talk about the two space techniques, and eventually about other space techniques like satellite laser ranging. Are there any immediate questions now concerning the terrestrial surveys?

Richard Langley: Again we have the same bubble chart (Figures 1, 1A). I have added contours which show one part in 10^5, 10^6, and 10^7. Sometimes it is easier to use these accuracy ratios rather than to talk about sub-centimetres and just to give you an idea of where these technologies fit in with respect to these sort of ratios. I am going to talk about space techniques exclusive of GPS. This cartoon (Figure 4) illustrates them. First I will talk about the Transit system, then say something about laser ranging, satellite laser ranging, and lunar laser ranging, and then I'll talk about very long baseline interferometry.

The principle of satellite positioning is illustrated in Figure 5. We have some point on the surface of the earth with a position vector, R, with respect to the centre of mass of the earth, and whose components are given in some coordinate system. We wish to measure that vector to identify the position of the point by making observations to a satellite which is at a position vector, r, in that same coordinate system. We are going to make measurements to get information about the satellite position vector with respect to the observation point, rho (the range vector), so that we have a closed triangle here, a vector triangle, three vectors. What we want to do is to solve for the station position vector R and we need, of course, two other vectors in order to do that. We need the position of the satellite with respect to the centre of mass of the earth, and also with respect to the position from which the observations are carried out. Now the observation techniques allow us in some way to measure directly or indirectly components of this vector, either its magnitude or its direction. By making enough observations, perhaps on a number of satellites, we can determine the relative position vector. What we need is information on the position of the satellite with respect to the centre of mass of the earth and having that information, plus our measurements, we can solve for the position of the station.

FIGURE 4

EXTRATERRESTIAL POSITIONING TECHNIQUES

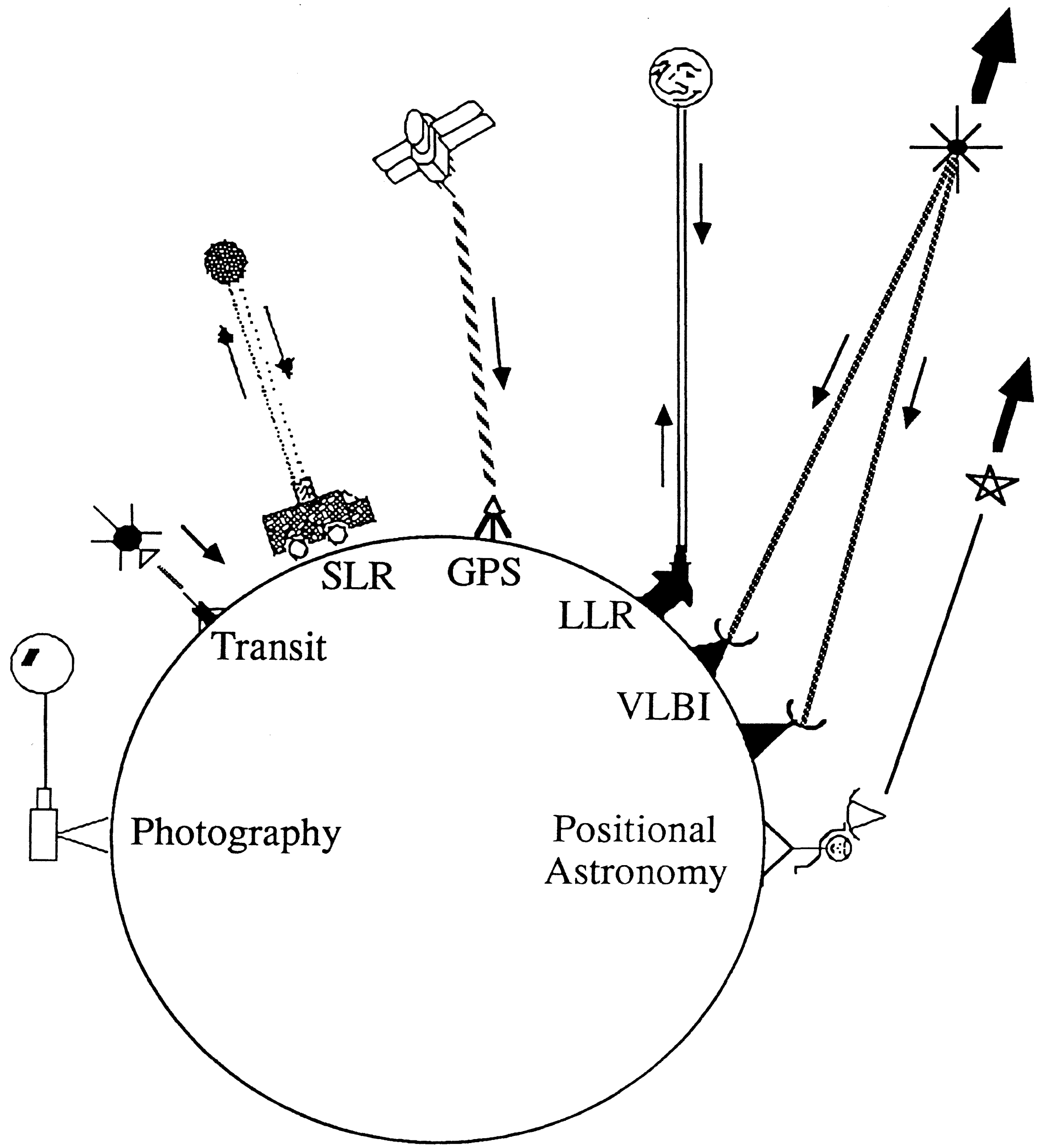
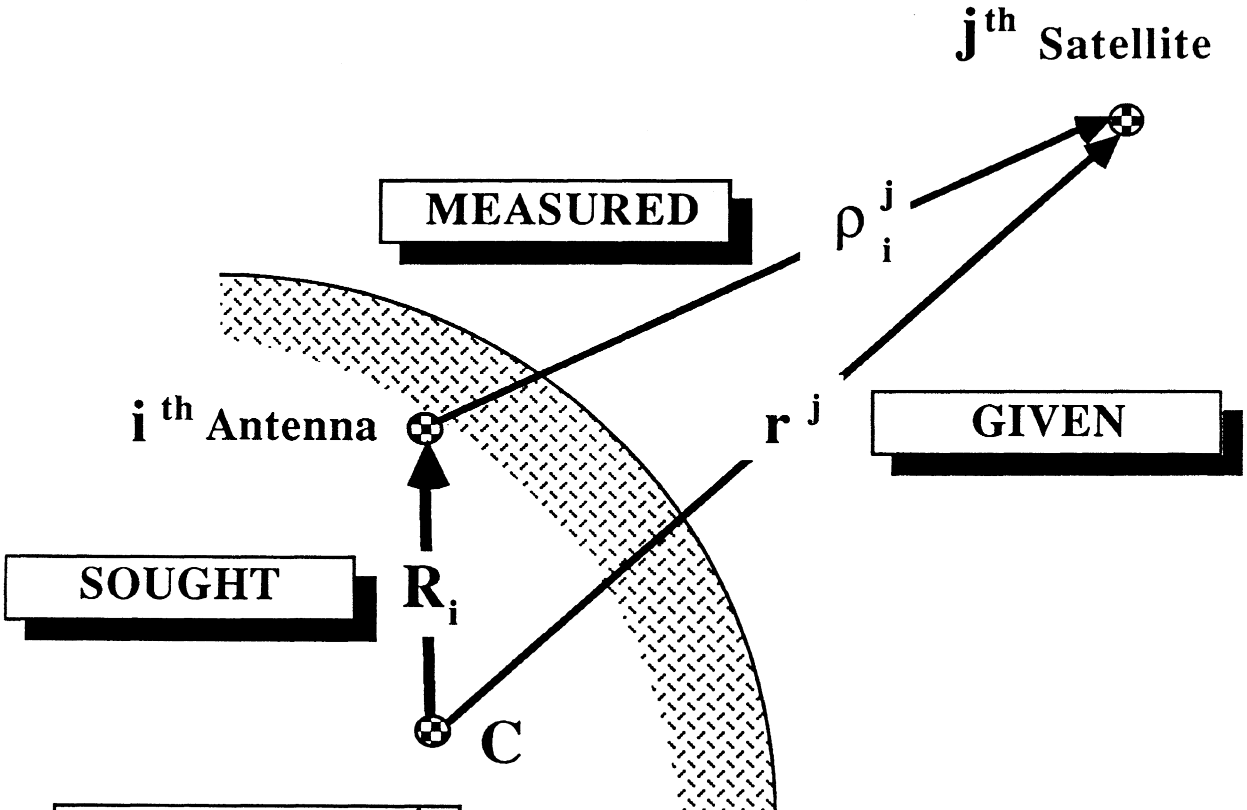


FIGURE 5

BASIC CONCEPT OF SATELLITE POINT POSITIONING



$$R_i = r^j - \rho_i^j$$

R_i is the position vector of the i th antenna

r^j is the position vector of the j th satellite

ρ_i^j is the range vector between the two.

I will first talk about the Transit system. Figure 6 illustrates the three segments of the Transit system. We have basically the user here with his receiver, receiving the signals transmitted by the Transit satellites. We have the satellites themselves and we have a ground control network which monitors the behaviour of the satellites, determines their orbits, uploads the information on the orbits to the satellites so that the satellites can subsequently broadcast that information to the users. The Transit system consists of a number of satellites. At present there are half a dozen or so in orbits with heights of about 110 km, which means that they orbit with a period of about 107 minutes. A pass over a user lasts normally 18 minutes or so during which time the user receives the radio frequencies (for geodetic work the two frequencies used are 150 MHz and 400 MHz) and the Doppler shift or integrated Doppler shift of those signals as received by the user is recorded along with the information transmitted containing the description of the satellite orbit. The user combines that orbit information with the measurement to determine his position.

It is the Doppler principle that is used (Figure 7). Most of you remember the basic Doppler formula, the received frequency being changed as a result of the relative motion of the satellite and the receiver and it is the same phenomenon as that we experience at a railway crossing with a passing train going by and we perceive a change in the frequency of the train's whistle. If we were to plot the frequency of the train's whistle as a function of time, you would see something like this. The perceived frequency starts out being higher before the point of closest approach and then drops to some lower frequency. So generally we get a curve with a shape like this. The shape of this curve is a function of the distance of the observer from the railway track. If he is farther back, we get a curve like this which has a less dramatic change, that is the slope is smaller in an absolute sense. Basically this is how satellite Doppler positioning works, where the receiver can measure the Doppler shift, actually the integral of the Doppler shift since those measurements are less sensitive to various error sources, and from those measurements the observer can determine the relative position with respect to the satellite in just the same way that this person here can determine his relative position with respect to the railway track.

The Transit system (Figure 8) has been in operation now for a number of years. The history of the Transit system essentially starts from the orbitting of the first satellites back in 1957 when it was first realized that the phenomenon of the Doppler shift could be used for positioning. The U.S. Department of Defense initiated a program to launch a series of satellites that could be used for positioning the Poseidon submarines. It was quickly realized there would be a number of civilian benefits to this system so in 1967 the system was released for civilian use. 1970 saw the first land survey use of Doppler, in fact UNB had one of the first Transit receiving stations anywhere. Since that time there has been growing use of Transit. A number of organizations now use Transit for establishing controls or assisting with the establishment of controls in geodetic networks.

Figure 9 gives you an idea of the satellites that are up there at the moment. A number of satellites have been launched and these satellites, although they have a remarkably long lifetime do eventually fail and they have to be replaced. The last launch of Tranist satellites was this past summer, 3 August, when for the first time 2 satellites were launched simultaneously. One of them became immediately operational and the other is being stored in orbit for future use. It can be commanded to "turn on" when one of the other satellites fails. There are still 10 or so satellites in storage on the ground that could be launched to replace any of the existing satellites.

Figure 10 gives you an idea of the widespread use of the Transit system. The majority of users of the Transit system are not geodesists, not people carrying out geodetic surveys, but people who want to do navigation with the system and there are in excess of 60,000 receivers currently operating, of all types. Only a small fraction of those 60,000 are used for geodetic purposes, maybe something in excess of 1,000 at the present time. It is unlikely that we will see any significant increase in the number of those receivers as a result of the development of GPS.

What are the positioning capabilities of Transit, that is, how well can we position with the system (Figure 11)? If we observe just a single pass of a satellite over a station and we are on a slowly moving platform such as a slow moving ship, we might expect something in the order of 100 m, two-dimensional positioning. If we are at a fixed site, and we use the information on the orbit as actually broadcast in real time by the satellite, we might expect to get 20 m accuracy. Again this would be two-dimensional positioning only, i.e., horizontal coordinates. If we observe many passes over our station, say, 40 to 50 over a period of 3 or 4 days, and again used the information on the orbit as broadcast, we might expect to get 3 to 5 m accuracy, three-dimensional, horizontal plus the vertical. There is available through the Department of Defense a more precise ephemeris than that actually broadcast by the satellites. The broadcast ephemeris is a prediction of where the satellite is based on a history of tracking. But is possible to get a more precise indication of where the satellite is by collecting observations and analysing them and then determining where the satellite was in the past. So with some delay, one can get a more precise

FIGURE 6

TRANSIT SATELLITE POSITIONING

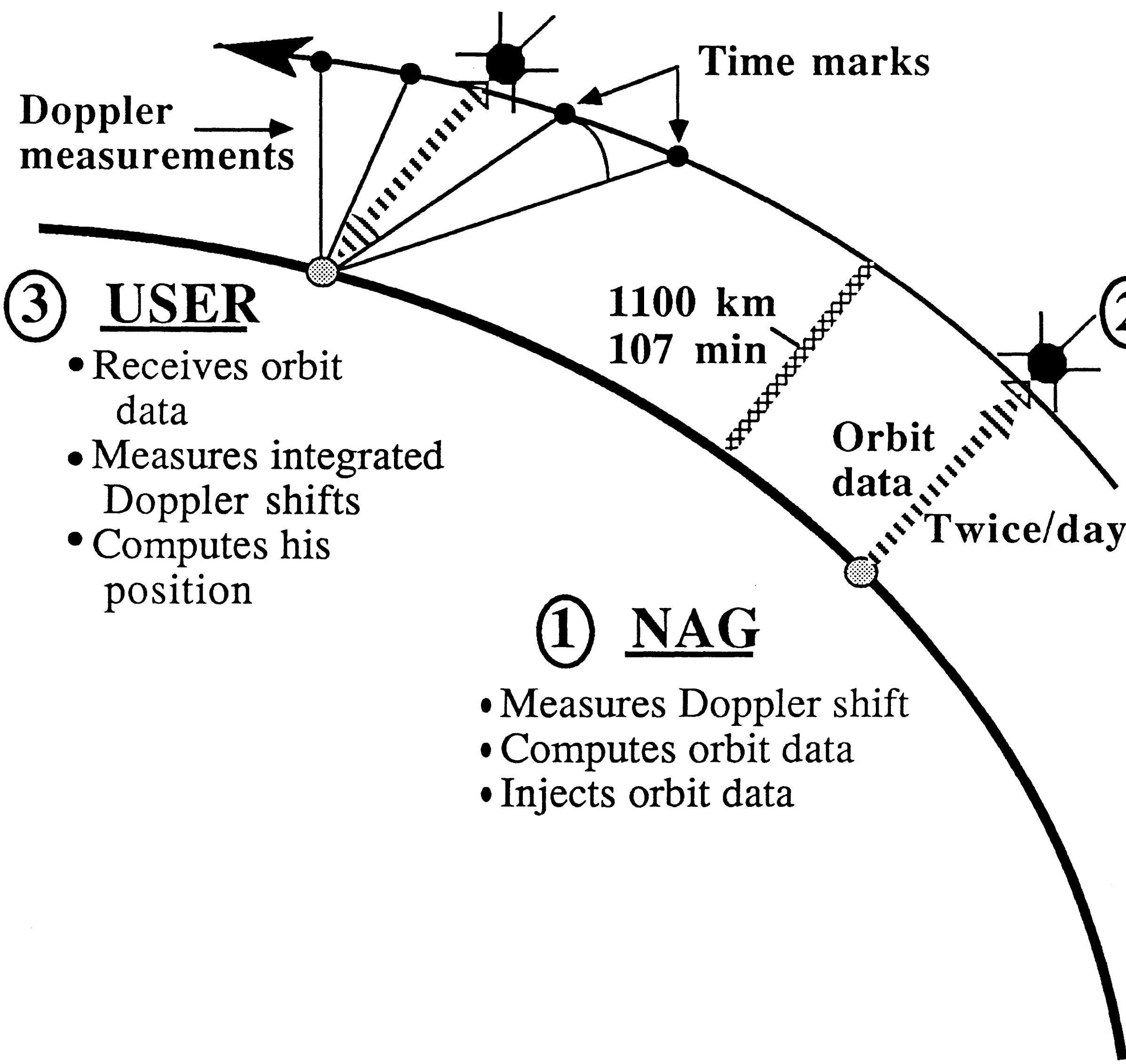
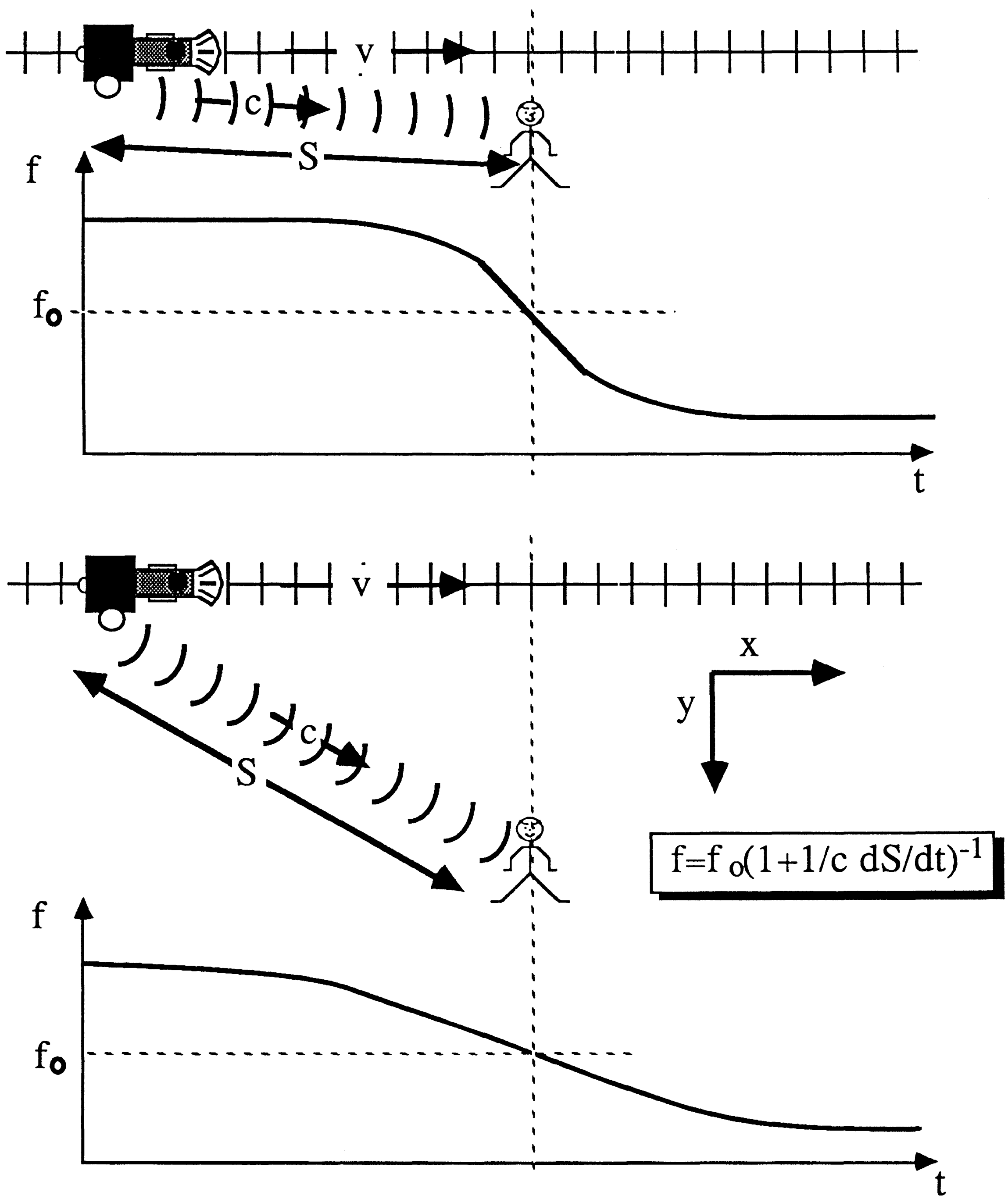


FIGURE 7

PRINCIPLE OF DOPPLER POSITIONING



NNSS HISTORY

1957	-	SPUTNIK ORBIT FROM DOPPLER
1958	-	CONCEPT OF KNOWN ORBIT, UNKNOWN RECEIVER
1961	-	FIRST SATELLITE
1964	-	OPERATIONAL
1967	-	CIVILIAN USE
1970	-	FIRST LAND SURVEY USE
1973	-	ADOPTED FOR NORTH AMERICAN FRAMEWORK
1976	-	WGS-72 COORDINATE SYSTEM

ACCURACY OF ORBITS

1959	5000 m
1963	100 m
1969	10 m
1976	1 m

SATELLITES

12	14 APRIL 1967 TO 20 NOVEMBER 1979
13	18 MAY 1967
14	25 SEPTEMBER 1967
19	27 AUGUST 1970
20	29 OCTOBER 1973
11	28 OCTOBER 1977

FIGURE 8

TRANSIT SATELLITES: RECENTLY ACTIVE, ACTIVE, AND PLANNED LAUNCHES

LAUNCH DATE	APL #	INT'L #	DMA #	TYPE-#	NASA #	ACTIVE?
14 April 1967	30120-36	1967 34A	58	OSCAR-12		NO
18 May 1967	30130-40	1967 48A	59	OSCAR-13	2807	YES
25 Sept. 1967	30140-56	1967 92A	60	OSCAR-14	2965	Failed Jan/84
1 March 1968	30180-52	1968 12A		OSCAR-18	3133	NO
27 Aug. 1970	30190-28	1970 67A	68	OSCAR-19	4507	Retired
29 Oct. 1973	30200-16	1973 81A	77	OSCAR-20	6909	YES
28 Oct. 1977	30110-36	1977 106A	93	TRANSAT-1	10457	YES
15 May 1981	30480-37	1981 44A		NOVA-1	12458	YES
11 Oct. 1984	30500	1984 110A		NOVA-3	15362	YES
3 Aug. 1985	30240 30300			SOOS-24 SOOS-30		Stored in orbit YES
1986				2 spare OSCARS TRANSAT-2		
1987				2 spare OSCARS NOVA-2		

FIGURE 9

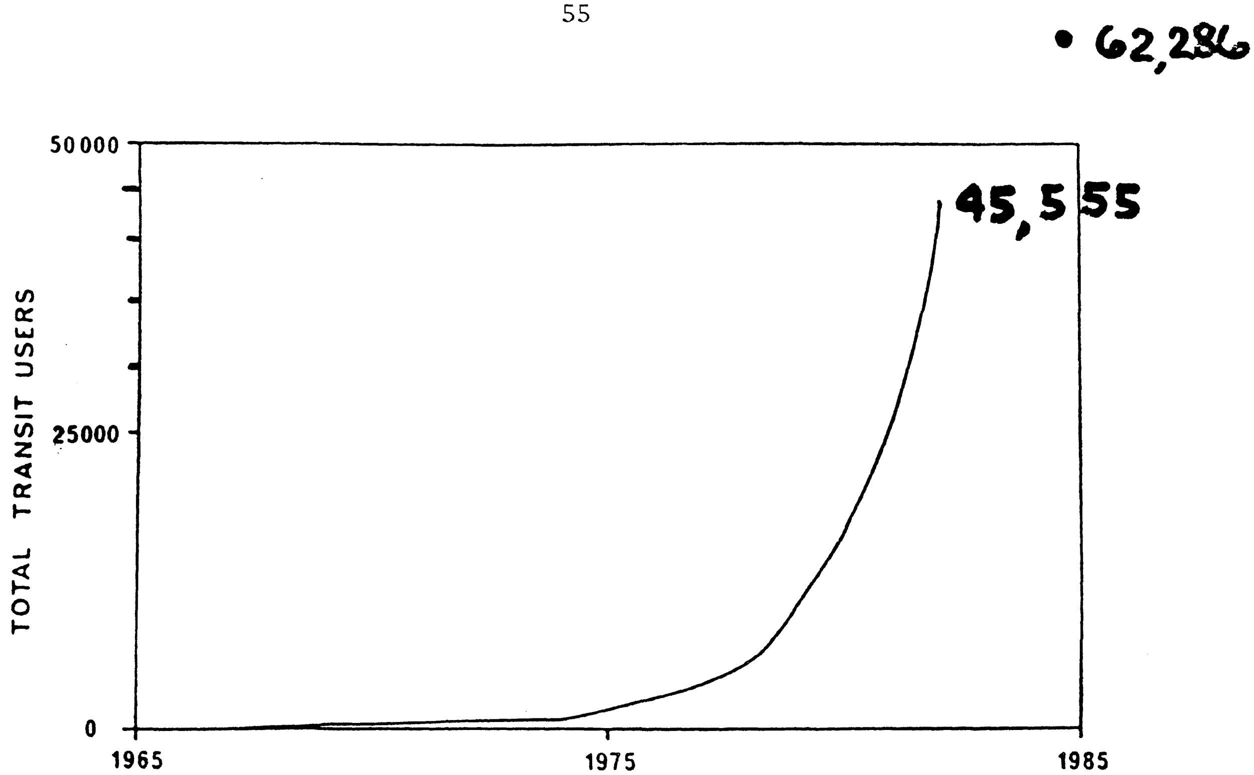


Figure 10 (a) - Growth in the number of nagivation and geodetic satellite Doppler receivers. After Hoar (1982).

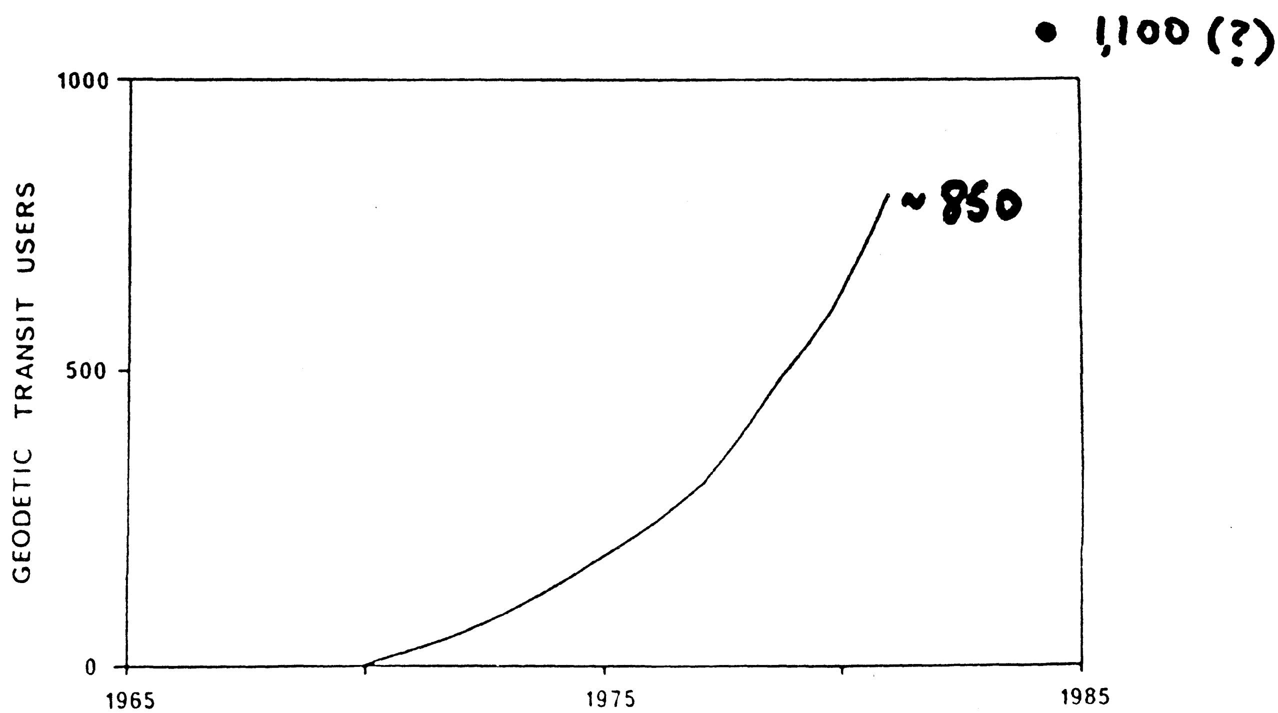


Figure 10 (b) - Growth in the number of geodetic satellite Doppler receivers alone. After Hoar (1982).

SINGLE PASS ERROR BUDGET

		Effect on Station Coordinates
1.	UNCORRECTED PROPAGATION EFFECTS	1-5 m
2.	INSTRUMENTATION	1-6 m
3.	UNCERTAINTY IN GEOPOTENTIAL MODEL	
	(a) BROADCAST	15-20 m
	(b) PRECISE	5-10 m
4.	INCORRECTLY MODELLED SURFACE FORCES	10-25 m
5.	UNMODELLED UT1-UTC EFFECTS AND INCORRECT COORDINATES OF POLE	< 1 m
6.	BROADCAST EPHEMERIS ROUNDING ERROR	6 M
	r.m.s. (a) BROADCAST	19-33 m
	(b) PRECISE	12-28 m

TRANSIT POSITIONING CAPABILITIES

100 m	- SINGLE PASS DATA ON A MOVING PLATFORM (2D)
20 m	- SINGLE PASS DATA AT A FIXED SITE WITH BROADCAST EPHEMERIS (2D)
3-5 m	- MULTIPASS DATA AND BROADCAST EPHEMERIS (3D)
50 cm-1 m	- MULTIPASS DATA AND PRECISE EPHEMERIS (3D)
30-50 cm	- MULTIPASS, MULTISTATION DATA WITH PRECISE EPHEMERIS (3D)

FIGURE 11

ephemeris, combine that with many-pass observations, and get considerably better accuracies, something like 50 cm to 1 m in all three dimensions. If one has a network of Doppler stations, again observing many passes, and again using the precise ephemeris, that 50 cm lower estimate drops to 30 cm. So this is currently the best one can do. This is relative positioning with Transit. Again, it is unlikely that we will see any major efforts in reducing the uncertainty here in the advent of GPS. Although in principle it would be possible with studies to reduce this down to 20 or even 10 cm by having a close look at the sources of error that contribute to this uncertainty, but it is doubtful that that will in fact be done.

Dave Wells: Although there is a lot of work along those lines going on in Hungary right now.

Richard Langley: That is true. Since they may not be able to avail themselves of GPS as quickly as perhaps some western countries, and Transit satellites will be up there for some time. However, perhaps not long enough to really be able to carry out some of the in-depth studies because the DoD intends to replace the Transit system with GPS by 1994. Figure 12 shows some excerpts from the U.S. Federal Radionavigation Plan of 1984. This is a plan established by the U.S. government to have some sort of unified approach to radionavigation techniques in the future. GPS is going to make a number of techniques redundant and the redundant techniques are going to be Loran-C, Omega, two navigation systems and Transit (which is used for both navigation and geodetic positioning). So any further development of Transit to increase its capability is probably not significantly cost beneficial given this 1994 cut-off date. We might see some minor developments, in fact at UNB we are involved in a minor development where we have upgraded the capabilities of an old Marconi 722-B receiver by interfacing it with an Apple microcomputer to control the receiver and record data. But apart from small developments like that I don't think anything terribly significant will be happening with Transit.

Let me move on to talk about laser ranging (Figure 13). The technique of laser ranging is very simple in principle. You have a laser that fires pulses of laser light to a reflector on a satellite. These pulses are returned and the time delay, how long it takes for the pulses to get from the the laser to the reflector and back, is essentially a measure of the two-way distance and if we divide that by 2 and multiply by the speed of light we will get the distance from the laser to the reflector and by recording a series of such distances and knowing where the reflector is, that is the position of the satellite to which the reflector is attached, one can determine the position of the laser. The most famous reflector of the laser signals is the LAGEOS satellite (Figure 14). It is a totally passive satellite (Figure 15), it has no electronic instrumentation on it whatsoever. It has a brass core which is surrounded by retroreflectors, 426 of them, and the total mass of the satellite, even though it is only 60 cm in diameter, is over 400 kg. A very dense satellite and therefore it has a relatively stable orbit. Something that is important to get high accuracy position determinations.

I would like to point out that satellite laser ranging is basically used for geodynamical purposes and it plays an important role in the NASA Crustal Dynamics Project, a project to determine on a world-wide basis tectonic motions in an effort to get a better understanding of these motions and the associated earthquake activity. In conjunction with this project, satellite laser ranging systems have been sent to various areas, something is excess of 30 sites have been occupied by satellite laser ranging instruments (Figure 16). There are several sites that are not marked on this map including sites in Spain, Switzerland, and Greece. Notice that Canada is absent. Canada has never become involved in the laser end of the Crustal Dynamics Project. We have concentrated instead on the use of VLBI.

Let us look at the error budget of satellite laser ranging (Figure 17). I will just draw your attention to the bottom line. It is believed that laser ranging is capable of repeatability of 4.5 cm on heights, and better than 2 cm repeatability on regional baselines of 400 or so km in length; on longer baselines spanning continents, it is still less than 5 cm on the determination of the length of those baselines.

In principle it doesn't matter whether you have the reflectors on a satellite or on the moon, and although you do need a more powerful laser in order to get a decent signal back and by a decent signal we mean at least 1 photon and that in fact is about all that does come back after sending 10^{18} photons to the moon (Figure 18). So you need a fairly sensitive telescope in order to detect at the 1 photon level. There have been a number of attempts to range to the moon and there are three reflectors that were left there by the Apollo astronauts plus 2 more placed there remotely by Russian spacecraft. The most successful lunar laser ranging installation is at the McDonald Observatory in Texas. There is over 10 year's history of ranging to the moon from that station. But several more have recently come on line including the ones in Hawaii, Australia, and France.

We turn lastly to VLBI (very long baseline interferometry). The concept of VLBI is shown on Figure 3. VLBI is an outgrowth of the development of technology by radio astonomers who wanted to develop more sensitive instruments, instruments with greater resolving power than previously available. One has

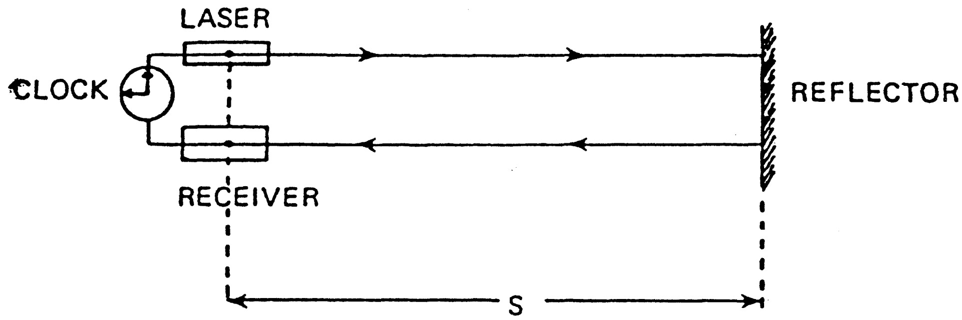
EXCERPTS FROM
U.S. FEDERAL RADIONAVIGATION PLAN–1984

LORAN-C	- military use of overseas LORAN-C to be phased out by 1992	) Final)
	- U.S. systems to be kept past year 2000	) Decision
OMEGA	- military use to be phased out by 1992	) in
	- to be kept operational until after year 2000	)) 1987
TRANSIT	- to be replaced with GPS by 1994	
	- about 62,000 commercial sets by end of 1984	
	- about 400 military users	
GPS	- fewer than 100 DoD GPS receivers predicted to be in use up to 1987	
TDRSS	- positioning capability:	
	• 30-50 m cross-track	) real
	• 150-250 m along-track	) time
	• 20 m CEP non-real time	
LANDSAT-D	- LANDSAT-D registration requirement: 15 m; later missions will require 2 m	
WGS-84	- supposed to have been available by December 1984.	

FIGURE 12

VERY PRECISE DISTANCE MEASUREMENTS CAN BE OBTAINED THROUGH THE USE OF LASERS

PRINCIPLE:

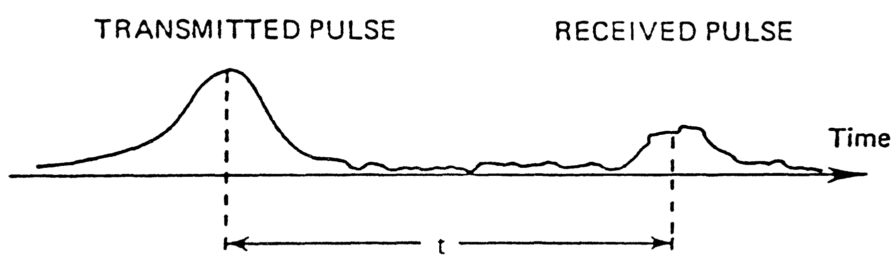


THE CLOCK MEASURES THE TIME t THAT IT TOOK THE LASER BEAM TO TRAVEL TWICE THE DISTANCE S BETWEEN THE LASER AND THE REFLECTOR. THEN

$$S = C \cdot \frac{t}{2}$$

WHERE C IS THE SPEED OF LIGHT.

PROBLEM:



THE PULSES' CENTERS MUST BE RESOLVED TO A HIGH ACCURACY BECAUSE C ≈ 30 CM/NSEC.

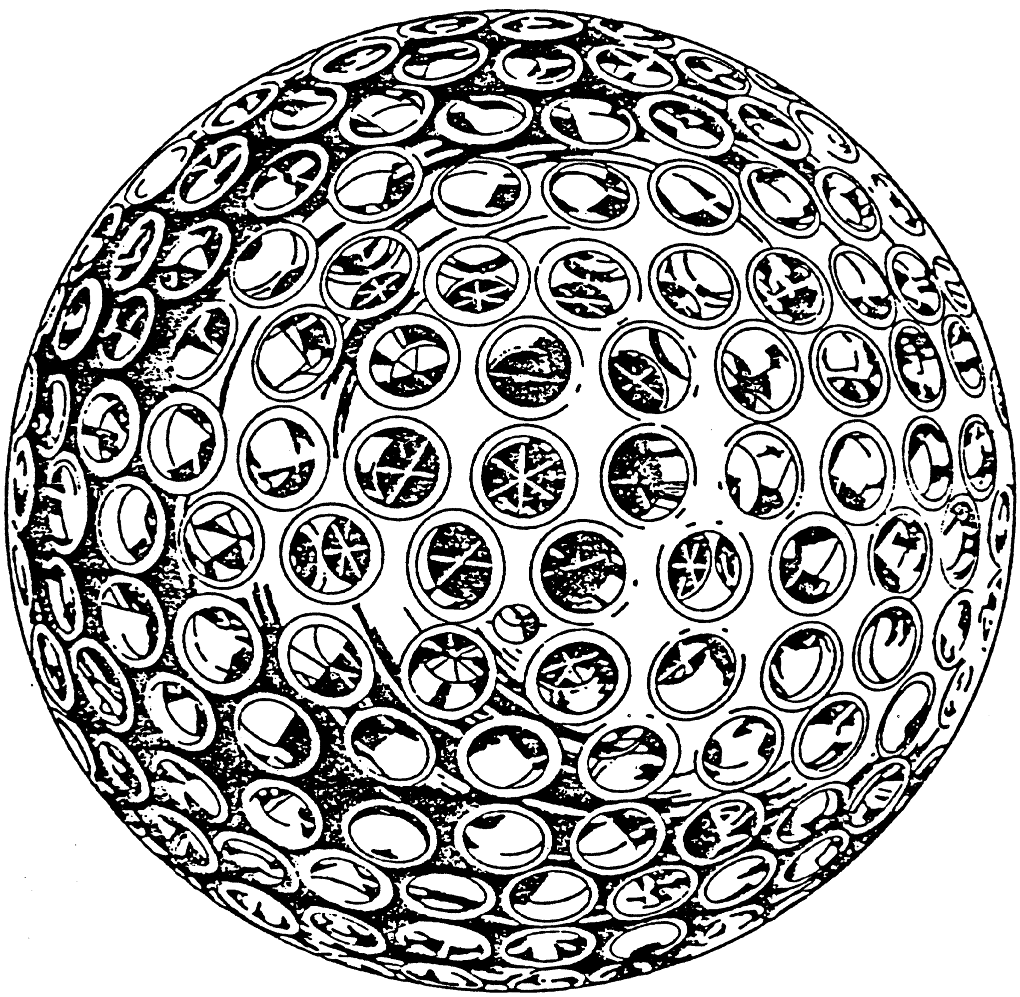
FIGURE 13

LAGEOS

(LASER GEODYNAMICS SATELLITE)

LAUNCH:	MAY 4, 1976	
SPACECRAFT:	SPHERICAL, 60 CM DIAMETER	
	406.965 KG	
	426 LASER RETRO-REFLECTORS, 3.8 CM DIAMETER	
ORBIT:	SEMIMAJOR AXIS	12265 KM
	INCLINATION	109.8 DEGREES
	ECCENTRICITY	0.004
	PERIGEE HEIGHT	5858 KM
	APOGEE HEIGHT	5958 KM
	NODE RATE	+0.343 DEG/DAY
	PERIGEE RATE	-0.214 DEG/DAY
	SEMIMAJOR AXIS RATE	-1.1 MM/DAY

FIGURE 14



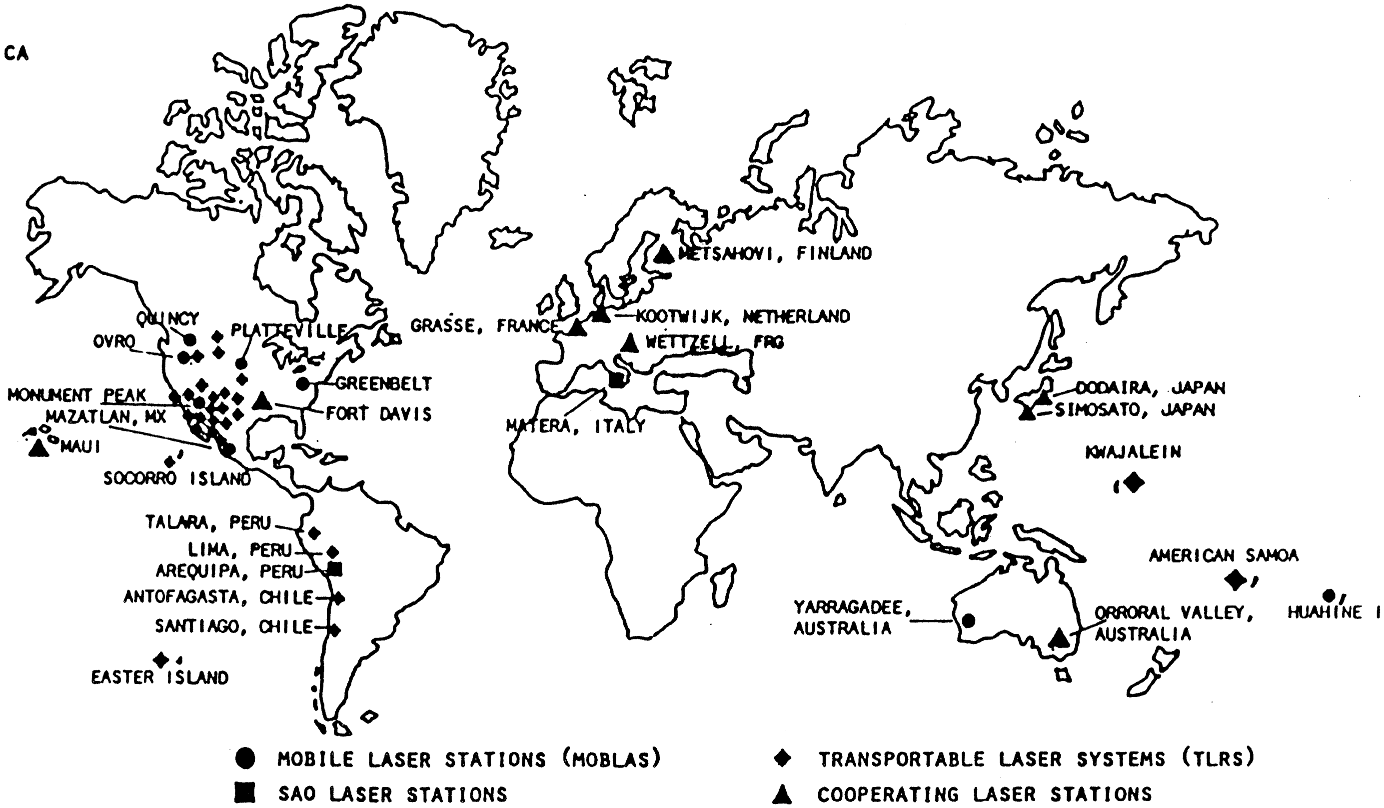
LAGEOS satellite

FIGURE 15

NASA CDP LASER TRACKING NETWORK 1982

NORTH AMERICAN TLRS':

OWENS VALLEY (OVRO), CA
GOLDSTONE (GDS), CA
VANDENBERG, CA
MT. WILSON, CA
MT. OTAY, CA
BLACK BUTTE, CA
FLAGSTAFF, AZ
YUMA, AZ
MT. HOPKINS, AZ
BEAR LAKE, UT
VERNAL, UT
CABO SAN LUCAS, MX
ENSENADA, MX



From: NASA Geodynamics Program: Annual Report for 1982

FIGURE 16

ERROR BUDGET (cm)

	HEIGHTS	REGIONAL BASELINES*	GLOBAL BASELINES
REFERENCE FRAME	1	0	1
GRAVITY FIELD (GEM L2 σ's)	2	1	2
10% EARTH AND OCEAN TIDES	1	1	1
ALONG TRACK ACCELERATION DERIVATIVE	1	0	2
10% OF H_2 AND ℓ_2 LOVE NUMBERS	2	0	2
100% OCEAN LOADING	1	0	2
100% ALBEDO RADIATION	1	0	1
SYSTEMS (surveys, biases, atm)	< 3	< 1.5	< 2.5
TOTAL (RSS)	< 4.5	< 2	< 5

* Relies mostly on simultaneous data

FIGURE 17

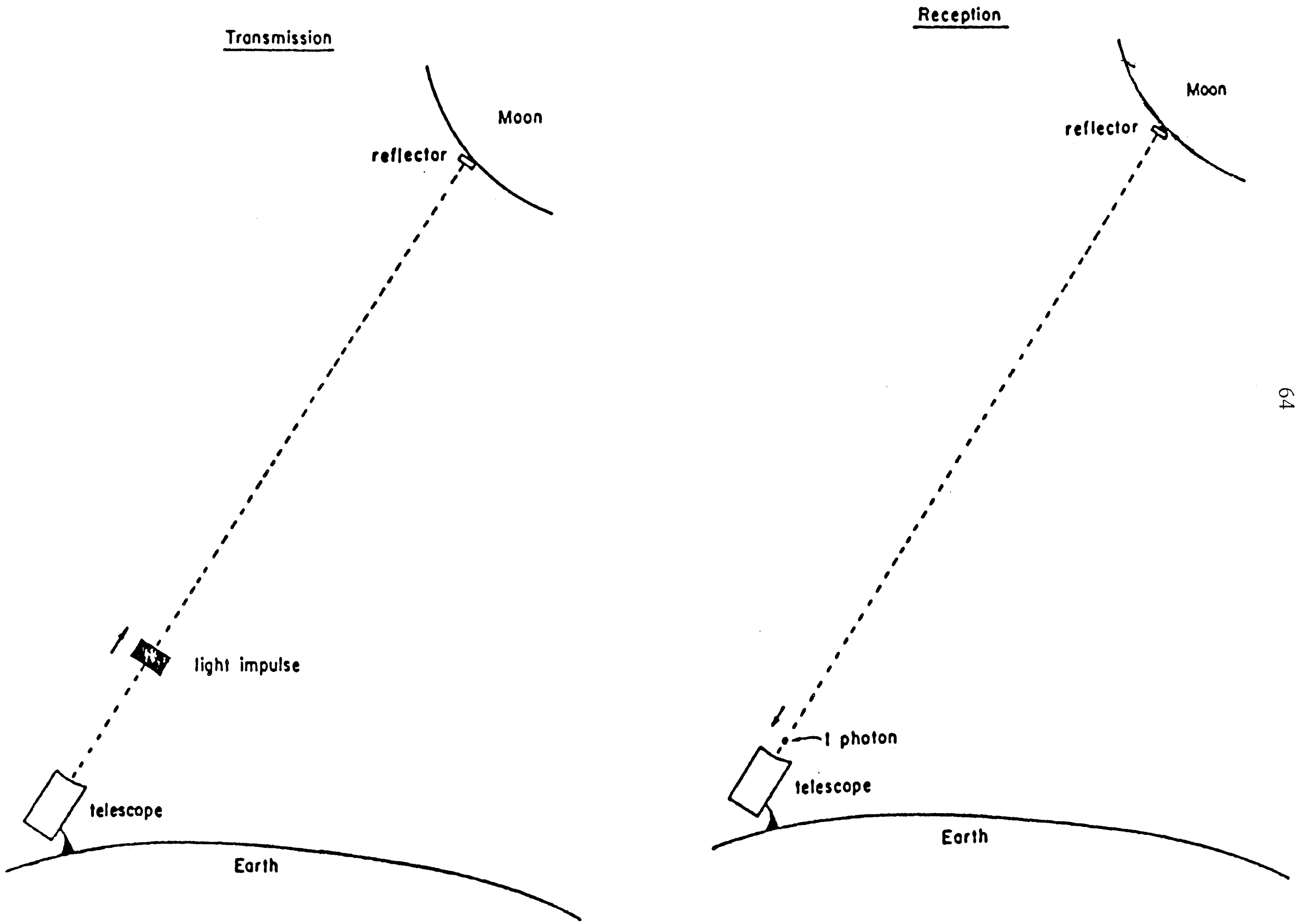

Transmission
Moon
reflector
light impulse
telescope
Earth
Reception
Moon
reflector
1 photon
telescope
Earth

FIGURE 18

two radio telescopes, two very sensitive radio receivers, usually at the focus of parabolic reflectors similar to those used in some backyard TV satellite receiving installations. Both radio telescopes, which are unconnected, observe the same natural radio source such as a quasar and the signals received independently at two stations, are recorded on taperecorders which are controlled by atomic frequency standards, such as hydrogen masers, and subsequently after the observations have been made those tape recordings are sent to a single site for processing where they are played back and one signal is multiplied by the other or cross correlated to determine the VLBI observables.

The basic observable is the delay that a radio signal experiences after it intercepts one antenna and before it gets to the second antenna. So basically, VLBI measures the time delay in the propagation of a wavefront from a radio source. That time delay, tau, is a function of the relative station-quasar geometry. If the spacing of the two antennas is given by the baseline vector **b** and the direction of the quasar is given by the unit vector **s**, then **b.s** is simply the delay multiplied by the speed of light. It is also possible to measure the time rate of change of that delay, but the basic observable is the delay. Subsequently, analysis of the delays and delay rates provides the baseline vector **b**. One could also determine from the observations the position of the source, the unit vector **s**.

There are many applications of VLBI (Figure 19). As I said, it was developed by radio astronomers, so, of course, there are applications in astronomy, but there are also applications in other branches of physics, such as general relativity. There are practical uses of VLBI. For research purposes, one can synchronize clocks very accurately using VLBI. NASA uses it for spacecraft navigation, and there are a number of studies in geophysics which can be carried out using VLBI. In this particular listing, I have geodesy of a sub-branch of geophysics.

How well can one do with VLBI? Here is an error budget (Figure 20). Again I will just draw your attention to the bottom line. In this case, we divided the error sources according to the length of the baseline. Short baselines, 200-400 km in length and longer baseline a factor of 10 longer—4000 km. With a short baseline we can talk about horizontal and vertical uncertainty in the baseline vector separately and for the horizontal component roughly 1-2 cm uncertainty. But because of the difficulties with the atmosphere, the uncertainty of the vertical is much larger, perhaps 5-9 cm, althought the upper limit is coming down, especially as one understands now the troposphere somewhat better than we did in the past. Further understanding of the troposphere involves instrumentation to remotely sense the effects of the troposphere. A number of groups are working on the development of water vapour radiometry so that we can remotely sense the constituents in the troposphere and then apply corrections to the VLBI data. On the long baselines, we are now just talking about the length, an order of 2-3 cm accuracy. To prove that that accuracy can in fact be obtained I have a plot here which shows repeated determinations of a baseline between Massachusetts and Texas. The series of observations covers about 3 years and we are looking at the individual determinations of the length of the baseline with respect to the mean and that is 2 cm between the ticks on the vertical axis. It looks like there may be some systematic trend to the baseline measurements. If you fit a best fitting straight line (Figure 21) you get something like -0.8 is – 0.1 cm per year and people are looking into whether in fact this does represent a true change of the baseline as a result of tectonic motion, perhaps some distortion that exists between Massachusetts and Texas.

Canadian involvement in VLBI has been going on since its development, in fact VLBI was a Canadian invention. A group of Canadian astronomers beat out an American group also trying to develop VLBI back in 1967. So Canada has been invovled in VLBI ever since. The most recent activity has been with the Crustal Dynamics Project which has seen the use of VLBI instrumentation at a number of world-wide sites. The first Crustal Dynamics Project observations in Canada were carried out one year ago at several sites in northern Canada in conjunction with a program to monitor regional deformation in southern Alaska. This map shows the sites that were occupied in conjunction with those observations. There was a site at Whitehorse which saw the use of mobile VLBI equipment, that can be transported in aircraft or on barges. Usually the dishes used in VLBI are large steerable parabaloids of 25 metres in diameter or even larger. It is possible to reduce the size of those dishes and to make mobile instruments which are maybe only 4 or 5 metres in diameter. JPL developed two such mobile instruments MV-2 and MV-3 and these were used at various sites in Alaska and/or Canada. The results are just now being looked at. The observations were repeated last summer and the idea is to go up every summer and carry out the observations so we will have a time history of measurements. Eventually we will be able to determine what the changes in those baselines are as a result of tectonic motions.

APPLICATIONS OF VLBI

- **RADIO ASTRONOMY**
  - ASTROMETRY
  - MAPPING
- **GENERAL RELATIVITY**
- **TIME AND FREQUENCY SYNCHRONIZATION**
- **SPACECRAFT NAVIGATION**
- **GEOPHYSICS**
  - PRECESSION AND NUTATION
  - UT1 AND POLAR MOTION
  - OBLIQUITY OF THE ECLIPTIC
  - SOLID EARTH TIDES
  - GEOPOTENTIAL
  - SEA SURFACE TOPOGRAPHY
  - GEODESY
  - TECTONICS (LOCAL AND GLOBAL)

FIGURE 19

FIGURE 20

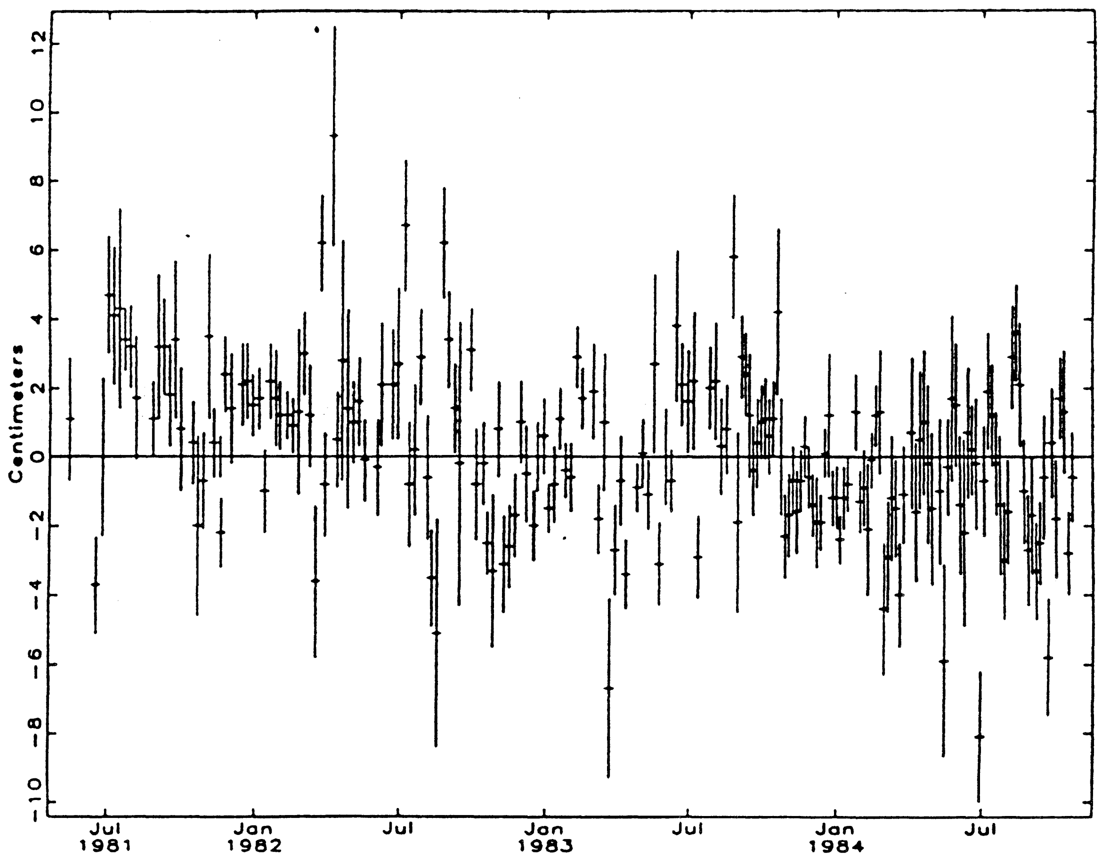
VLBI ERROR SOURCE SUMMARY

CONTRIBUTIONS TO "BOTTOM LINE" BASELINE RESULTS

	<---- 200-400 km ----->		4000 km
	SHORT Baseline -HORIZ-	SHORT Baseline VERTICAL	LONG Baseline -LENGTH-
INSTRUMENTATION	0.9 cm	1.4 cm	1.0 cm
IONOSPHERE	0.1	0.2	0.2
DRY TROPOSPHERE	0.1	1.5	0.5-1.0
WET TROPOSPHERE (1)	0.5/1.0	4.0/<9.0	1.5/<3.0
UT1/POLAR MOTION (2)	0-1.0	0.5/1.0	=0
SOURCE STRUCTURE	0.3	0.3	0.3
Aggregate RSS Estimate	1.1-1.7 cm	4.7-9.3 cm	2.0-3.3 cm

(1) First number assumes WVR, Second assumes the use of Modeling or Surface Meteorology data.

(2) Assumes 10-20 cm a priori data (e.g. POLARIS, SLR or LURE).



WESTFORD - FORT DAVIS BASELINE

Best-fitting straight line: -0.8 ± 0.1 $cm \cdot yr^{-1}$

FIGURE 21

An activity involving VLBI for the future is the national active control point system being proposed by the Geodetic Survey in conjunction with GPS. Dave may talk more about this subsequently. I will just point out at the moment that this active control point system involves the use of radio telescopes at several sites around the country to establish the zero order framework for the coordinate system into which all the GPS measurements or observations will then be tied. With VLBI one can determine the relative positions of the radio telescopes down to the cm level, therefore establish a very good framework for the GPS observations which will be carried out in conjunction with a number of active control points. Perhaps Dave will mention more about that. I have a few more viewgraphs that compare the recent accuracies of GPS vis-à-vis VLBI but it perhaps would be appropriate to show those after the introduction of GPS.

Dave Wells: Why don't you just put it on—the one you showed me just now—so that it is a starting point for GPS.

Richard Langley: In conjunction with the VLBI observations up north, in 1984, a GPS campaign was carried out using the same sites that were occupied during the VLBI campaign. Either before or after the VLBI observations, people went in with GPS receivers and occupied these same points. Therefore, separate determinations of the relative positions of the sites with GPS were obtained and could be compared with the results from VLBI. With our colleagues at the University of Bern in Switzerland, we have compared the GPS and the VLBI results and we show here the comparison for 5 of the stations that were involved. Because GPS and VLBI use different coordinate systems, one has to rotate one coordinate system with respect to the other and perhaps do a scale transformation so that you are detailing with consistent determinations of the baselines. After you do such a transformation, you can then see how well the GPS and VLBI results agree. The disagreement is shown here for the positions talked about, latitude, longitude and height. You can see that the biggest difference is something like 6 cm here in the latitude of the Whitehorse site and if you look at the r.m.s. of all these values, you get 4 cm. So that VLBI and GPS appear to be agreeing at the 4 cm level over baselines of several hundred kilometres in length. We think that is good news for GPS. With simpler, cheaper instrumentation, we appear to be approaching the capabilities of VLBI. Dave will talk now more about GPS.

Dave Wells: We really should have the inertial now.

Adam Chrzanowski: Do you want inertial then GPS?

Bill Robertson: Richard, just before we move on, VLBI seems to be extremely accurate under the transcontinental basis. Are you aware of any measurements that are included in the national network, in the geodetic network?

Richard Langley: There are baselines on the U.S. side that were incorporated in NAD83. There was some interest on the part of the Geodetic Survey to incorporate some Canadian measurements but the only measurements that we had of any value were between Penticton, B.C., and Algonquin Park. That's one baseline. I am not sure if they thought it was worth while incorporating one baseline into the Canadian part of the re-adjustment given the possible differences between the VLBI coordinate system and Doppler and so forth.

Mary Ogilvie: Could you put on that cartoon, the first cartoon of the earth. Tell me again the difference between Transit and GPS.

Richard Langley: They are entirely different systems and Dave will be talking all about GPS.

Dave Wells: With Transit, we have only one satellite at a time, so we have to track it over a period of time to get enough observations. With GPS, we track many satellites at the same time, and therefore we can get positions continuously. So with that in mind, why will GPS have a greater impact on surveying than Transit? Well, it goes right back to this first point (see Figure 22). Because we get continuous positioning, then there will be a lot more people wanting to use it.

Surveyors have always found for control networks that Transit has been useful. As we saw from Richard's receiver population curves, there are perhaps only about a thousand Transit receivers used in surveying and less than 100,000 receivers used around the world for everything. Most of those are inexpensive, book-sized Transit receivers that are put in fishing boats and this kind of thing. That is

WHY GPS WILL HAVE A GREATER IMPACT THAN TRANSIT ON SURVEYING

GPS PROVIDES POSITIONS CONTINUOUSLY

» more applications (air, land)
  » larger market
    » more investment in receiver development
      » lower cost receivers
        » more sophisticated receivers

MORE SOPHISTICATED MICROELECTRONICS

» lower cost receivers
» more sophisticated receivers
  (not enough incentive to redesign Transit)

MANY SATELLITES TRACKED SIMULTANEOUSLY

» cancellation of receiver timing errors
» better geometry
  » shorter tracking period to meet specifications

180 DEG PHASE MODULATION (TRANSIT = 60)

» "codeless" tracking of carrier

ORBITS 20 TIMES HIGHER THAN TRANSIT

» longer baselines
» smaller Doppler effect
» smaller gravitational perturbations
» smaller atmospheric drag perturbations

FIGURE 22

where most of the 60,000 receivers have gone. There is a much larger market for general aviation. That has been estimated at about 300,000 receivers world-wide. And if we get (I'll mention this a little bit later) to the stage where we can actually start thinking about having GPS receivers together with electronic charts, and whatever, as an option similar to an air conditioner in our car for about $500—and all the car manufacturers are looking at this as an upscale option by the end of this decade—then we are talking about millions of receivers, not just 60,000 or 100,000. A lot of manufacturers have seen this market and have said it's worth putting some effort into trying to compete in this market.

So there is a lot of receiver development going on, but there are also a lot of companies in competition. I will have a list of some of them in a few minutes. Because of that, there is likely to be lower cost receivers than you would ever get from Transit, and more sophisticated receivers than we could ever get from Transit, because the market demand for Transit just isn't there.

There is another thing that we have to look at, and that is the microelectronics trend. We know that microelectronics get more powerful and less expensive and more reliable each year or decade, and if Transit had been invented this year instead of in the 1960s, undoubtedly the Transit receiver would also be smarter, cheaper, and so on. But there isn't enough of a market for manufacturers, who already have a viable Transit receiver, to redesign it. So, as Adam said about conventional survey instrumentation, we are not going to see any major changes in Transit because it has a limited life and it really can't compete for other reasons with GPS. However, GPS is coming at the time that microelectronics development is further along and therefore, for that reason as well, we are going to get lower cost receivers and more sophisticated receivers.

Going back to the point that I made earlier, we track several satellites at the same time and this allows us to do a few things. First of all, one of the major sources of errors with Transit, the thing that really limits it at the 30-50 cm region that Richard mentioned, is the timing in the receiver. It is impossible to get precise timing no matter what you use. We had some data that used a maser clock that we were looking at last week, and it was terrible, I mean terrible by GPS standards, that is, tens of centimetres of noise in the data. With cesium clocks it is the same thing. I have some plots that we can look at if you are interested this afternoon on that kind of thing. When we track several satellites at the same time with GPS, we can cancel the receiver timing errors. We can't do that with Transit, because we are only tracking one satellite at a time. Also when tracking several satellites at the same time with GPS we get better geometry for our fixes instead of having to track one arc and from one pass get only enough information to calculate a two-dimensional fix. As Richard pointed out, we can get much more than that from GPS. As well, because we are collecting data from several satellites, we can have a shorter tracking period than we would have with Transit. As an example, to get the 30-50 cm accuracy with Transit we have to track for approximately 2 days; to get down to the centimetre level with GPS, we need track for only 1 to 5 hours.

There is a more technical difference between GPS and Transit with the way in which the signals are modulated. The GPS signals are modulated with 180° phase-shifts, which can be considered as phase reversals; but the Transit signals are modulated with a 60° phase-shift. It is only with the 180° phase-shift that there are techniques that allow us to track the signal without knowing anything about the modulation, the code, or the message. As a result, there are receivers, like the Macrometer which you have probably heard about, that are called codeless GPS receivers. This would be an impossibility with Transit because of the phase-shift. Finally, we have the GPS orbits which are 20 times farther from the earth than Transit. This allows us to have intervisibility over thousands of kilometres so that we can have longer baselines, even interconnecting continents if we wish. It means that the Doppler effect is much smaller. Again, as Richard showed in Figure 7, as we walked farther away from the train track, the change in the sound at closest approach is much less and that is the same thing with the GPS. In this sense, the Doppler effect is something that makes it more difficult for us to use the measurements to model the orbit. So that the orbit is something we can more easily model from the measurements and therefore get orbital corrections. Also, being farther from the earth, it is less affected by the irregularities in the earth's gravitational field and by the drag in the higher density of the atmosphere with the Transit heights of 1000 km rather than the GPS heights of 20,000 km. So there are a number of reasons. I am sure there are a lot of other ones that are of less importance than these.

I think the major reasons for GPS are the first two. That there is a market for GPS that is well beyond the traditional markets for Transit, and that surveyors who will be piggybacking on this will benefit from the fact that there will be a lot of sets sold for aircraft and perhaps for cars. In addition, we are entering the GPS era later on in the evolution of microelectronics technology.

That is the introduction I wanted to give. The rest of what I would like to talk about is, first of all, to give you some sort of a status report about where we are now with GPS, particularly in terms of the satellites themselves and in terms of receivers, and try and make some predictions as we go. Then I will talk about the particular aspects of GPS that are of importance for control surveys, namely the differential developments. I have three things to talk about there: (i) the Geodetic Survey of Canada initiative of active control points or an active control system; (ii) some results that were generated at a test in Gaitherburgs, Maryland, on the 12 and 13 August, that I have here from Ben Remondi of the U.S. National Geodetic Survey; (iii) and the prospects for the broadcast of differential corrections for GPS. This is of more immediate benefit or concern to marine users in moving vessels, but I think that there are some implications in terms of broadcast technology, and so on, that we should look at for the distribution of GPS data in real time or control surveys as well.

Let's look at Figure 23 which shows the GPS satellite constellation. There are launches every now and then of GPS satellites, but the first satellites were launched in 1978. There were 4 satellites in orbit by 1980, and there are now 6 active satellites in two orbit planes. What this gives us is coverage in this area of the world of about 5 hours a day, which is adequate coverage for control surveys baseline determination. There are some places in the world where there isn't any coverage at the present time, or at least very inadequate coverage. As I have mentioned, the satellites are in orbit 20,000 km above the earth with a 12 hour period. There is a repetition of the pattern on the opposite side of the earth every 12 hours. The satellites that are in orbit now are prototype satellites, and they will be replaced with the production satellites with the planned replacement starting next year. The launch sequence is to have 3 or more Spaceshuttle missions that put 21 operational satellites in orbit; 18 to be active and 3 to be active spares. It means that they expect the system to be operational with only 18 satellites, but they want to have a little redundancy in case there is a failure.

The plan is that sometime before the end of 1989 all the satellites will be in orbit and operational. The plan is that as long as the prototype satellites are operating they will be incorporated into the intermediate constellation and then they will be phased out as they are replaced by the production satellites. So that sometime after 1989 there will be full coverage and the system will be operational. The status right now is that full operation it is not guaranteed. The U.S. Department of Defense, who is producing this sytem, reserves the right to turn it off or play with it or mess around with the signals at any time without notice. We would anticipate, though, that the DoD would be responsible about that and give notice to the users, unless they really wanted to be perverse. I think they see that there is a market growing there and that, although it is a purely military system from the development point of view, there would be some public relations benefits to the U.S. military to foster the civilian market as well.

Murrray Banks: Dave, is this system paid for totally by the United States?

Dave Wells: Yes, totally paid for by the U.S. Department of Defense.

Murray Banks There are no international agreements at all?

Dave Wells: No, nor were there for Transit. Transit is a U.S. Navy system and, until 1967, they were reluctant to release the details of the system and approve civilian use of it. However, it was released in 1967 and there hasn't been one minute of perverse interruption to its operation since. There are many communities amongst the manufacturers, depending on what kind of receiver they make, predicting either dire things because they think they will sell more of their type of receiver or more optimistic scenarios of what may or may not happen to the GPS signals once it becomes operational. We'll be getting into some of those things a little bit later.

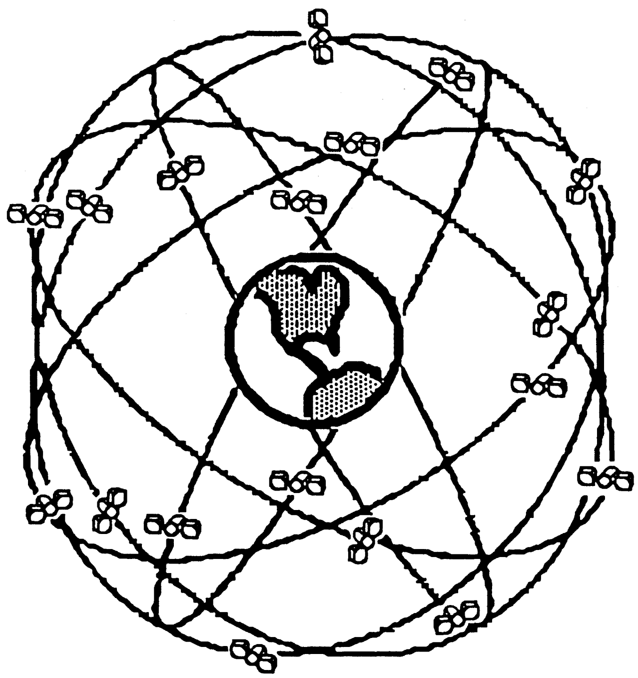
Mary Ogilvie: Dave, on the same topic, is there any inclination by anyone else to put up some satellites to protect themselves again possible problems?

Dave Wells: Yes, I'll talk about that after I have talked about GPS. There are two or three proposals. The Russians have a system that actually has more satellites up than the U.S.—the already mentioned GLONASS. They have 12 satellites in orbit already that look just like GPS except they aren't as good.

To return to the GPS constellation, Figure 24 shows the planned launch schedule. Right now we are still with the last launch of the prototype satellites. I think there is still one that was supposed to be launched in August but it wasn't launched was it Richard?

FIGURE 23

GPS CONSTELLATION IN 1990



- 18 satellites, plus 3 active spares
- 6 orbit planes
- 12 hour period
- 20,000 km height
- (almost) full coverage
  (24 hours per day everywhere in the world)

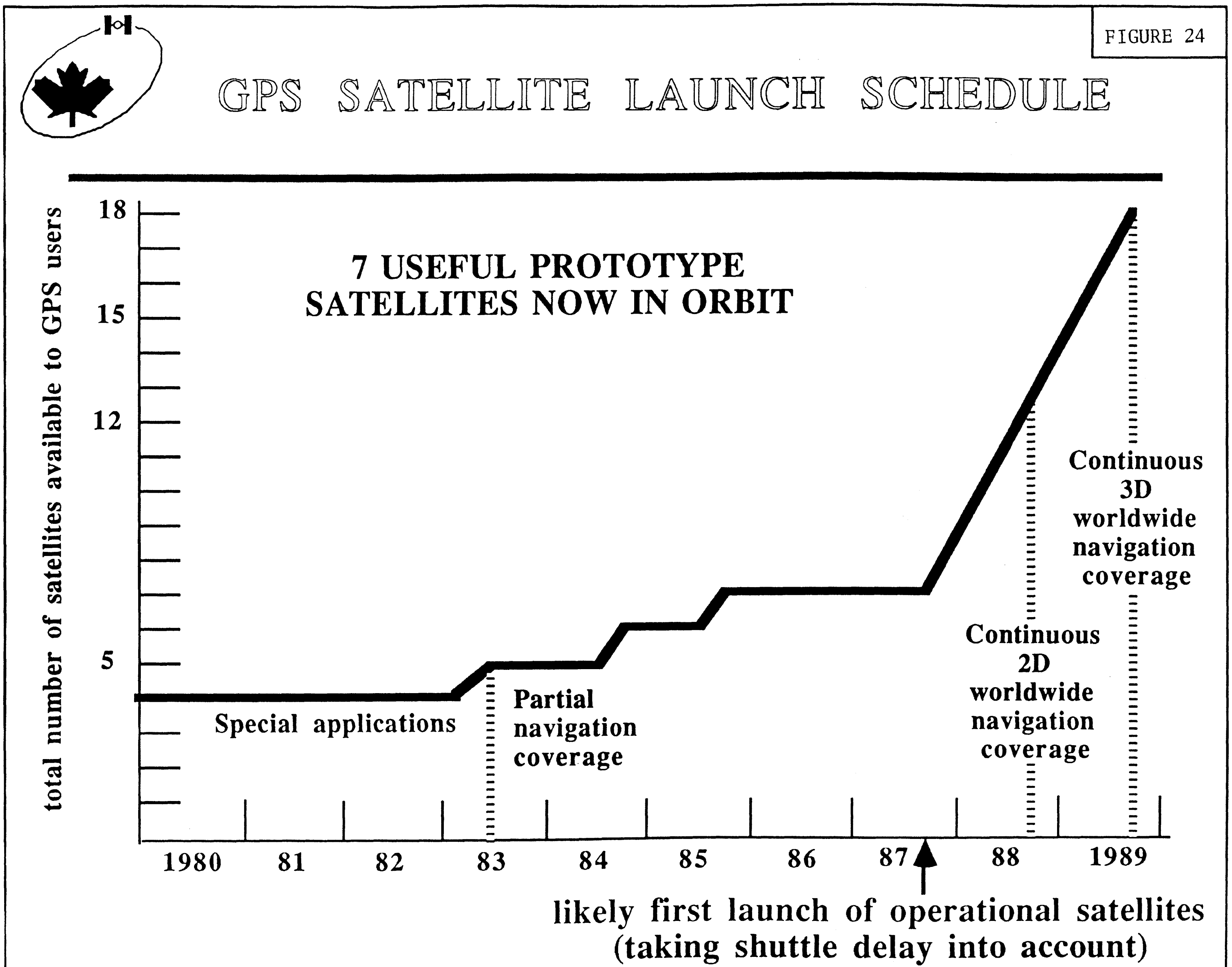


FIGURE 24
GPS SATELLITE LAUNCH SCHEDULE
7 USEFUL PROTOTYPE SATELLITES NOW IN ORBIT
total number of satellites available to GPS users
18
15
12
5
Special applications
Partial navigation coverage
Continuous 2D worldwide navigation coverage
Continuous 3D worldwide navigation coverage
1980
81
82
83
84
85
86
87
88
1989
likely first launch of operational satellites (taking shuttle delay into account)

Richard Langley: It was supposed to be sometime in the fall of '85.

Dave Wells: So the last of the prototype satellites are still to be launched. They built 11 of them, one of them exploded on launch and the others have all be successfully put in orbit. Several have failed for various reasons, mainly the early ones with some power supply failures. But there hasn't been a failure since 1980.

So Figure 24 shows this nice sort of smooth curve. There will in fact be 3 or 4 jumps in there between late '86 and late '88 but I think that is now probably late '89. This again is critically dependent upon the success of the Spaceshuttle missions and things like that. There could be all kinds of hitches there. It might drag on to the early 1990s. But the plan is that before the end of the decade the system will be operational with 18 satellites plus 3 spares. So that gives you a little bit about the satellites. Let's talk a little about receivers now.

There are all kinds of receiver types, as shown in Figure 25. I don't want to try and give you all the inns and outs of them, but there are three basic kinds. One is the **code-correlation** type. All the military receivers are code-correlation receivers. There is a **code-phase** type. That is a special development of the Jet Propulsion Laboratory in California and a spin-off company called ISTAC. Finally, there are the **squaring** types of receivers.

The squaring goes back to what I mentioned about the phase modulations. The phase modulations on the GPS signal are 180° and you can model them as plus or minus 1. If you square a minus 1, you get a plus one, and plus one means you are not changing the signal. So if you square the signal that is coming in, that is, if you mix it with itself and multiply it by itself, you end up with a signal that has no modulations on it. You have probably heard about the P-code and the C/A-code, as shown over here under code-correlation. These are things that are meant to prevent unauthorized use of the signal and, in fact, if you square, all you get is the carrier. You can make measurements on the carrier, but you don't know where the satellite is. You don't get any information about the satellite orbit and you don't get any pure range measurements to the satellite. This is the way the Macrometer works. It is a squaring type receiver. The Macrometer that is in commercial use, or has been in commercial use since 1982, is the signal frequency **Macrometer**, the **V-1000**.

There is in the works a dual frequency receiver; I don't think you can actually buy one yet, but there is talk about it. The reason you want to go to 2 frequencies is the ionospheric refraction which can only effectively be compensated for by making measurements on 2 frequencies. Now if you are talking about short baselines, maybe as much as 50 km apart, the ionospheric refraction is going to be so similar at both ends of the baseline that it will cancel when you difference the observation on both end of the baseline, so you don't really need a dual-frequency receiver. If someone is doing a survey over a limited area, the two frequency receiver is an unnecessary complication. On the other hand, if you want to set up a control system for the Maritimes where you have some monitor points and you have individual surveyors or LRIS survey crews going around positioning things with respect to this building here in Fredericton, or whatever, then a dual frequency capability would be a useful thing. I guess the rule of thumb is that you get something like 1 ppm on a single frequency receiver and probably 1/10 or an order of magnitude better than that with a dual-frequency receiver.

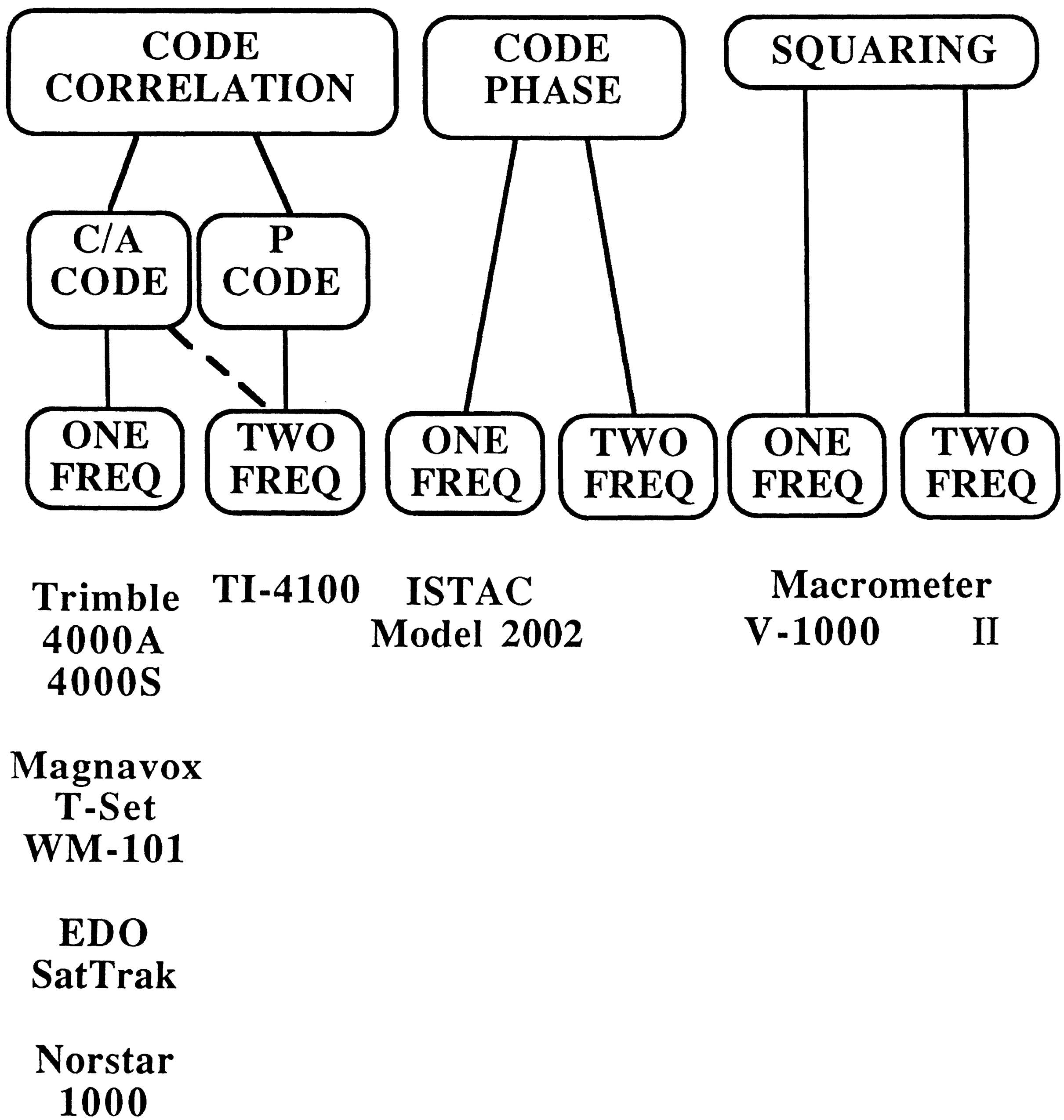
The **Macrometer** is the workhorse that has probably put in more control in North America at least than any other GPS receiver to date. For example, in Alberta the provincial government contracted out a survey of 200 control points last year, 250 control points this year, and they intend to have that kind of a contract out each year for the next few years.

If we move over to the other side and look at the code correlation, one deficiency with the squaring type receiver would be that you don't get any information about the orbit. That has to come from somebody else. In the early days, the Macrometrics people had a pipeline into the Defense Mapping Agency and got the precise ephemeris of the post-computed GPS orbit parameters through the back door. They now have a tracking network of their own and they sell that as an optional service to their customers. What can be done is to have one code-correlation receiver at a monitor station that just tracks the message and provides that to the users of the system. In fact, that is what is being done in several places now. The code correlation is the official technique—the military technique. It is still a good technique.

In our experience, there is not much to choose between code correlation measurements using, for example, the **Texas Instruments 4100** receiver that I have listed there and the squaring type measurements using the Macrometer. They give about the same quality of positioning. It appears that whether you have a C/A-code receiver or a P-code receiver, you still get about the same quality of carrier phase information which is the stuff we really need for geodetic positioning. That is all you get from squaring receivers. You get that as a by-product from the code-correlation receivers.

FIGURE 25

GPS RECEIVER TYPES



You see a long list on Figure 25 under the single-frequency C/A-code receivers and a very short list under the two-frequency P-code receivers. The **TI 4100**, I believe, is the only P-code receiver that will ever be designed for civilian use. They have such a hold on the market now that it isn't worth any other manufacturer's time or expense to try and develop a competing receiver. So everyone is putting their eggs into the C/A-code basket. The reason is that the military has announced that the P-code will not be available to non-military users after 1989. It is freely available now, but once the final constellation is in orbit, the P-code is to be encripted so that even the TI 4100 won't be able to track it. The TI 4100 is capable of dropping back to a C/A-code mode; it will just shift to the other column if and when that happens.

This is an example of the controversy, depending on which manufacturer you talk to. If you talk to the TI people they say: Oh they will never turn off the P-code as they never did that with Transit. You talk to the guys who have put their eggs into the C/A-code basket and they say: There is no way they are going to hand out the P-code to anyone. So, we'll have to wait and see.

One of the ones in the list under the C/A-code, the **Trimble 4000A**, is the best selling receiver in the world to date. They have sold 138 receivers this year. The 4000A, however, does not bring out the carrier phase measurements that we need for the most precise geodetic positioning. If you want to get under 5 m, you need to get the carrier phase. You can use the code itself for about 5 m orbit positioning. The **4000S**, is supposed to be out this month (October 1985). Well, first it was supposed to be out in August and it has slipped a couple of months. It is the version of the Trimble that is supposed to have the phase observations thus it becomes a viable control surveys tool. Several Canadian companies have been using many Trimble 4000As for things like rig positioning, where the control requirements are not in the centimetre region but the metre region, and it is capable of that.

Magnavox has got together with Wild and they have announced the **Wild-Magnavox 101** receiver. Geodetic Surveys of Canada has ordered 2 of them. They were supposed to be delivered by the end of 1985. Wild-Magnavox are probably slipping by about 6 months.

Collins Radio or **Rockwell Collins** are the people who beat out Magnavox for the large military contracts. They are going to be providing 20,000 receivers to the U.S. military and they have done a pretty good job of designing receivers. They have a receiver that in fact was in Halifax a couple of weeks ago that they are selling for something under $20,000 as a black box. They don't want to get into the software business, they don't want to get into the interfacing business, so they sell it as a sensor unit with some plugs on it, no front panel, and you build it into your equipment.

There are several other people who have at least announced receivers. **Litton** have said they will have a survey set, but it is probably a couple of years away. They have a picture of it, I have a slide of it, but it is an empty box. **Sercel** in France have actually sold 10 receivers capable of geodetic work, and they say they will have 70 more built over the winter, half of which have been committed for sale already. But they are charging an awful lot of money. We will get into prices a little bit later.

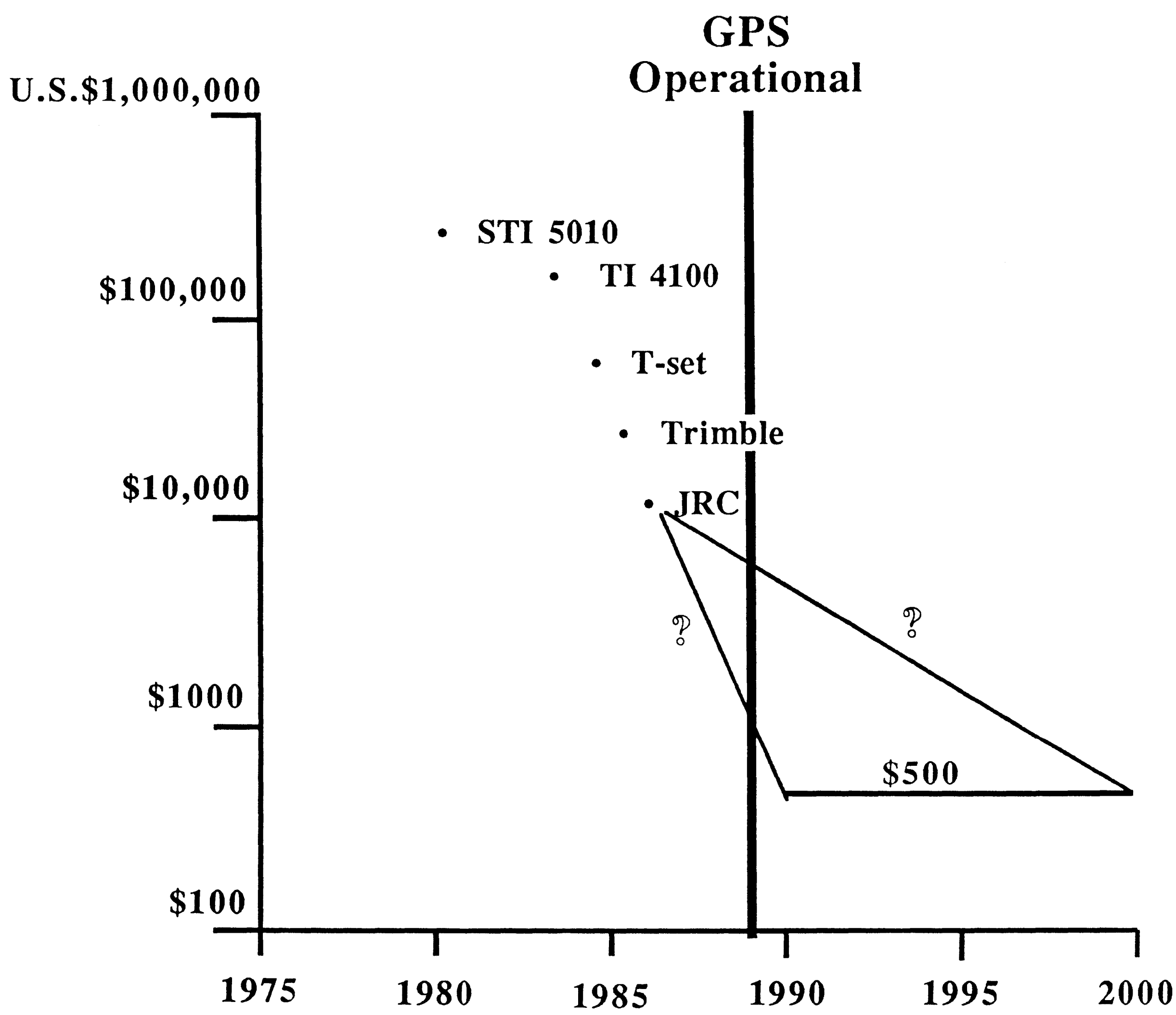
Let's go back to the centre column of Figure 24. This is the special code phase technique that was developed at the Jet Propulsion Laboratory and is now being marketed by this company called **ISTAC**. They started off with a things called a **Model 1991** which was marketed by Geo/Hydro, the company that had also been leasing Macrometers. I think the reason was that the Macrometer ownership changed from a small company in Boston to Litton Aerospace or Aero Services, and they were a competitor for Geo/Hydro so they were looking for another product to market. I haven't heard about the 1991 being much of a success, and it was very high priced—1/4 of a million dollars for a set. However, ISTAC has since come out with the **Model 2002**, or at least announced it. I don't know if it has actually been built yet, but they have a much more realistic pricing policy.

Figure 26 gives an overview on the prices. The **Macrometer V 1000** with single frequency was originally announced at $100,000 each and you needed two of them with processors for $50,000, so you're talking about a quarter of a million dollars just to start as your baseline. The **TI 4100** is about $140,000 U.S. and again, if you want to measure baselines, you need two of them. This $140,000 does not give you the tape recorder you need which is another $20,000, and so on. So again you are talking of getting close to a half a million dollars. **Trimble's** is $25,000. That is why they are selling 130 of them. **Wild-Magnavox 101** has been announced at $90,000, but there are hints that Magnavox is running scared and they may very well reduce that price because of competition forces. Getting back to the **ISTAC 2002**, they have come in at about the $55,000 price level for their no-option version.

Let's have a look at what has happened to GPS receiver prices over the last few years. The first civilian GPS receiver available was the **Stanford Telecommunications 5001** and it cost $250,000 for 1 receiver that was capable of tracking only one satellite at a time. This was a very slow and not very useful receiver. Then the **TI 4100** arrived in 1983 priced at about $150,000. The **Magnavox T-set** is

FIGURE 26

GPS RECEIVER COSTS



essentially a Digital Equipment VT100 terminal with an LSI11 computer built into it. This is a standard DEC product, with 1 circuit board for Magnavox that is a 5-channel GPS receiver. This T-set is priced at about $50,000 U.S. and they are making a profit at that. I suspect that would drop to about $25,000 once they have brought the Wild-Magnavox 101 in as a competitor. The **Trimble** is, as I said, about $25,000. The cheapest receiver I know of at the present time is the **Japan Radio Corp**. receiver for $12,500. EDO Corporation in Calgary, which is the new version of JMR, were fairly lively in the Transit game at one time. They have bought a JRC receiver, repackaged it as a surveying receiver called **SatTrak**, and announced it just a couple of weeks ago; they haven't put a price on it yet.

In 1978, when the first GPS satellites went up, in the Hewlett-Packard research labs in California, a couple of bright engineers got together and built a GPS receiver during a research project. They took it out and tested it driving it down the streets of San Francisco, with an antenna on the roof of their car, and found that in fact there was a very puzzling discrepancy. It looked as if the positions they got from GPS, following the street map they had, indicated they were doing the right thing but there was one place where it went away from the map in a very systematic way. They couldn't understand it. They went and had a look at what had happened and it was the map that was wrong. There had been some construction and the street had been changed. They were able to track the width of the street as they drove in San Francisco in 1978. The last line in the article they wrote in the U.S. *Journal of Navigation* in 1979 said: "There was no reason why we cannot build a GPS receiver for $500 by 1990."

There was an interview in *Aviation Week*, with the president of Trimble, about what happened to those bright guys at Hewlett-Packard. They went to management and said here is a market we should consider getting into. Hewlett-Packard looked at it as a possibility and said, well it may be a market but it is not one that is compatible with our philosophy so why don't you guys do something about it on your own and we'll give you the license. So the bright guys went away and formed a company that has now become Trimble, and the President of Trimble was interviewed in August 1985 about their newest receiver which is a lot less expensive than the 4000 series that I mentioned. He said that within two years they expect to have the entire receiver-processing circuitry on a single chip. That is not too far fetched.

The **Magnavox T-set** I mentioned with one circuit board has about 10 chips per receiver channel. Collapsing those 10 into 1 does not sound as if it is out of the question. They are asking $30,000 for their new, cheap, small receiver. That is the price if you buy one of them but they will sell them to you for $1,000 each if you buy 10,000 of them. So what they are really in the game for now is recovering their development costs. In terms of production costs, we are down at the $1,000 level now. So the question is: When will the market volume get up high enough that we will actually be able to buy these things for $500? There are those who project 1990, as the guys from Hewlett-Packard did in 1978, and there are those who say it will be the end of the century before we see the $500 GPS receiver. Who know. There is really no difference between the kind of receiver that would be built for $500 to fit into an automobile, or whatever mass market there may be, and the kind of receiver we need for surveying as long as the receiver provides the carrier phase measurement that we need.

There is a company in Stuttgart, West Germany, that I visited the summer of 1985, who are competing for this automobile market. They have a receiver under development that will be about the size of a hardcover book. They have decided, just in the last few months, that there is enough of a payoff for them to make a few minor design changes to bring the phase out as an optional data item. Thus they can tap into a wider market. I think there are prospects for us to have GPS receivers a little earlier which will be much less expensive than the $10,000 receiver we were talking about.

Differential development. I don't have any viewgraphs on this, but what has happened in the U.S. is that there is talk that this P-code will be restricted. Let's go back to the design blunder that the GPS people made at the beginning. The P-code is a 10 MHz modulation or 10 megabit modulation per second, and the C/A-code is a 1 megabit per second modulation. The 10:1 ratio in the rate of these two modulations will lead roughly to a 10:1 ratio in the uncertainty with which the range of measurements can be made from the two types of modulation. Thus when we are talking about the military type of receiver, the code-correlation receiver, the mistake was made by saying that if you have a P-code receiver you might get your positions as accurate as 10 m, and that means because of the 10:1 ratio in the modulation rate that we will get only 100 m with the C/A-code. Well, ignore the fact that there is an error budget. The error budget has many more terms in it than the actual measurement uncertainty itself, such as refraction, timing, and so on. Those are common to both. So 10 m has been found to be essentially true with P-code tracking with 1 receiver. With C/A-code you don't get 100 m, you get 16 m. This is again because they overlooked the fact that there was a root sum squared term in their approach in the error budget. This has caused a lot of embarrassment. This response has been to say: now we are going to take the P-code away because that gives too much strategic advantage to potential adversaries, and we can't even leave the C/A-code the way it is. We're going to have to somehow intentionally put something in there to mess it up.

This is all discussed in the Federal Radionavigation Plan that Richard referred to. They have all kinds of euphemisms for screwing up the C/A-code. At first it was called "denial of accuracy", then they felt that was too negative so they now call it "selective availablility". Whatever! The intention is that the **selective availability** mechanism, whatever that is and that is something that has not been released yet, will be such that the surveying application, where you have two receivers and you measure baselines between them, will not be affected. Now, that's the statement that we hear. It is still a little bit of a cloud on the horizon. Until they actually implement it and we actually test it, there is no way of knowing for sure exactly what influence it will have. However, among the civilian community, as led by the U.S. Coast Guard who, if Loran-C is shut down, see that GPS can play a very significant role in harbour approaches, for instance, for marine navigation, in instrument landing approaches for air navigation.

One of the proposals for GPS which is being seriously looked at by the Canadian and American coast guards is to keep the St. Lawrence Seaway open year round. How does GPS do that? Well, it isn't the ship's hull that is the problem with the ice in the Seaway. Icebreakers can keep the ice open and the ships could still get through year round, but the floating aides to navigation, the navigation buoys that mark the channels, get hauled off position by the ice much more quickly than the ice would damage any ship's hull. That is the reason why a ship going through the ice cannot keep in the channel during ice conditions. If there is an alternative, in other words, if they can precisely position themselves by some other technique, and GPS is not the only option that is being looked at, very fancy radars are another technique, then it would be possible to keep the Seaway open all year round. That won't be good news for Saint John or Halifax, but it would be good news for the grain shippers, and Chicago, and places like that.

A committee was set up by an organization called RTCM—Radio Technical Committee Marine—under a fellow called Rudi Kalifas at the Transportation Research Centre which is part of the U.S. Department of Transportation in Cambridge, Mass. What they have defined are the standards for the broadcast of differential corrections for GPS. Their final report is due out October 1985. They specify just what kind of communciation link, what kind of radio frequency should be used, what kind of data format should be used. We contacted several manufacturers in the last month or two who already have plans for implementing these standards in their own receivers. This means that there will be real-time GPS receivers available by the end of the decade. The original intention for this is for marine navigation, air navigation, things like that, but I think there are implications for control surveys. There is one message of 8 types that have been defined so far, that will be of this carrier phase from a monitor site to all kinds of users. There is a trend toward developing the technology that will make this kind of application of differential GPS for surveying as well as for navigation a reality with the next few years. That is one of the three points I wanted to make about developments that tend toward a differential survey capability.

The second point is one that is again a report I received just a few weeks ago (actually it is dated October 1985) of some test that were done in July and August in the U.S. The title the authors have given to the technique is "How to get relative GPS measurements to centimetre accuracy in seconds of observations." We have talked about 1 hour, 5 hours, and so on; they are talking seconds. What they essentially do is to set up two receivers at known points and observe for an appreciable length of time, maybe an hour or maybe less than an hour, so that they finally establish the baseline. Then they take one of the receivers and move it around. They have to be careful that they don't shade the antenna, they don't lose lock, they don't have any cycle slips on the carrier phase measurement they are making. They describe in some detail how they put it amd some guy on the roof of a car and drove off with them.

What I ask you to look at is their table 5. The numbers in table 5 indicate that the true values minus the computer values for some control points, that were up to 0.5 km apart, are all less than 2 cm; 1.9 cm is the largest discrepancy. Each of these was measured with approximately 1 minute of data. They revisited the points several times in the experiment. What this is really saying is that this coherent phase record, that we use to do our single baseline determination, also gives us sufficient information that we can actually move around to various control points in a local area and get precise relative measurements in an area. The whole thing is a small scale survey of one or two kilometres extent at the greatest.

Looking at this in terms of LRIS control along the highways, if you establish two stations a couple of kilometres apart, observe them long enough to get that baseline, and then move one of the receivers, carefully and not shading the antenna, then you can place it on control points that are very densely spaced and get the positions within, they claim, centimetres in seconds.

Now these are initial tests. A lot of this was a proposal made only in April of this year. There have been some tests made in Austria already in the summer of 1985. So it is growing; it is something that looks valid. They seem to have validated the theoretical proposal they made in April 1985. It looks as if this is an unexpected way of using GPS.

The third thing that I want to mention is the Geodetic Survey of Canada active control system. Again I will pass around the Terms of Reference of the committee that is to propose this, and I will just read what our terms of reference are. They are the definition of the applications or scope of the applications of GPS; the design of a GPS positioning system for Canada; operation and maintenance concerns; management of the system; definition of the data; definition of how to collect the data; what hardware and data sources to use; processing and analysis data management; dissemination; and other aspects. There is a meeting of this committee I'll be going to on Tuesday, 29 October 1985 in Ottawa. I hope that one of the things that we can bring up this afternoon is the concerns LRIS would like to have expressed at that meeting.

Murray Banks: Dave, would that be with the view of putting up our own system?

Dave Wells: Not our own satellite system. Using the GPS system, but going back to the picture that Richard showed of those 20 circles covering Canada. He indicated that 3 of those could be co-located with VLBI antennas or radio telescopes but the intention, those 20 circles, were intended to be 20 GPS receivers. Now, 20 may be too many. We may be able to get away with less than that. The way to start it off, however, was to say well, every provincial capital had better have one for political reasons. That was 10. Then the territories and the arctic islands, and so on. Thus this is just a conceptual idea at the present time. Getting down to design studies and looking at just how many would actually be needed and doing some experiments, and so on, are, I think, the things that will be coming up in the next few years.

Murray Banks: What I have trouble understanding is why would the U.S. put up 21 satellites for the benefit of Canada and other countries to be used without any strings attached unless we were putting some money into it. That concerns me because you said earlier they could shut these things off.

Dave Wells: We could talk about that but I think that the Transit system is an ideal example of what has happened already. The Transit system was and is still a purely military system. There has been, in some quarters in the U.S., some resentment that many of the major advances in the civilian use of the Transit system have come from other countries, Canada being one of them, and that most of the receivers that are built for the Transit system are now available from Japan thus what is the benefit for the U.S. There have been some complaints about that. However, when it comes back to GPS, there was a move to have user charges in which you would pay $400 a year for a license to get the C/A-code and $4000 to get the P-code. That was demanded by the U.S. Congress saying they needed cost recovery on this thing, because it is costing $8 billion to put those satellites up. So the U.S. Department of Defense took a serious look at it. I've got some documents in my office about the arguments for and against user charges. The DoD finally concluded that it was going to cost them more to collect the user charges than they were going to collect. If there existed $500 receivers, charging $400 each year to use them was going to have a depressing effect on the market. So I think the conclusion in the U.S. has been that they had better try and keep ahead technologically and try a get a greater market share this time than they did with Transit. However, as we have seen, Japan Radio Corp. already has the cheapest receiver on the market.

Murray Banks: So you are not too concerned yourself about losing access?

Dave Wells: There is strong pressure to keep the signals available at some level for civilian use. We can get into some of the people, for instance, the Texas Highways Dept. is one of the great pushers. They have written letters to every congressman and to the Secretary of Defense, saying that this is the only way they are going to be able to keep track of their control on their highways in Texas, and that they are using GPS now and intend to use it in a greatly expanded way in the next few years, once all the satellites are up. Thus and if GPS is turned off, they are going to scream bloody murder at everybody they can, because this is something the taxpayers paid for and should benefit from, and it doesn't hurt the U.S. in the strategic security to allow them to use it the way they want to use it.

Murray Banks: Using the squaring receiver type the military shouldn't be too concerned.

Dave Wells: No, they are not too concerned about the C/A-code either.

We'll just end up this section by looking at some of the proposed alternatives to GPS. I have some slides, a little fancier than this, but the information is all here.

The Russian version of GPS is called GLONASS for Global Navigation and Satellite System. They are talking of having up to 12 satellites in 12 hour orbits. The orbits are about the same height as the GPS orbits. The frequencies are about the same as the GPS frequencies, however, they don't have precise frequency standards in the satellites as GPS does, so they are only good for two-dimensional, not three-dimensional, navigation. They can't compute accurate heights. They have about 100 m accuracy instead of 10 m accuracy, which is the military, real-time, supersonic bomber positioning accuracy of GPS. The Russians launched 3 satellites in 1982 and they launched their 12th satellite in 1984. They have 6 in one plane and 6 in another plane, so there is potentially double the number of satellites up that GPS has. There have been some rumours that some of the people in the U.S. who have developed receivers, particularly MIT with the Macrometer, have looked at the possibility of tracking these things, in addition to GPS satellites. I think that would be a very interesting thing—to have a combined receiver that could track both GLONASS and GPS satellites—because then we would have an even wider choice of geometry. We could choose satellites in a little more optimal way. However, I proposed that to Magnavox and they thought I was out to lunch.

There is another system, just like GPS, which has been proposed by the European Space Agency. It is called NAVSAT (see Figure 27). It looked like it wasn't going anywhere until there was a flurry of activity this summer prompted by the new initiative of the European Common Market for high technology; Phoenix I think it is called. This was one of the contenders as a major high technology project, however, the last word I had was that it has fallen through yet again. The idea here was to have something that again looked very much like GPS as far as the orbit was concerned, but the signal structure would be very different—that you would in fact have what was called a *bent pipe*. That is, all the signals you tracked as a user were reflections from a fixed monitor. It wasn't a passive system. GPS just broadcasts and we listen: one receiver listens and another receiver listens and then you bring the signals together and compare them. Here the signals would actually be generated on the ground and the user would listen to something that was actually transponded by the satellites. They had a number of ways of using it: you could use a ranging code, or you could use the carrier, depending on what kind of price-tag you wanted on your receiver. The idea was that it would be a purely civilian service so there wouldn't be the concerns about it being under military control.

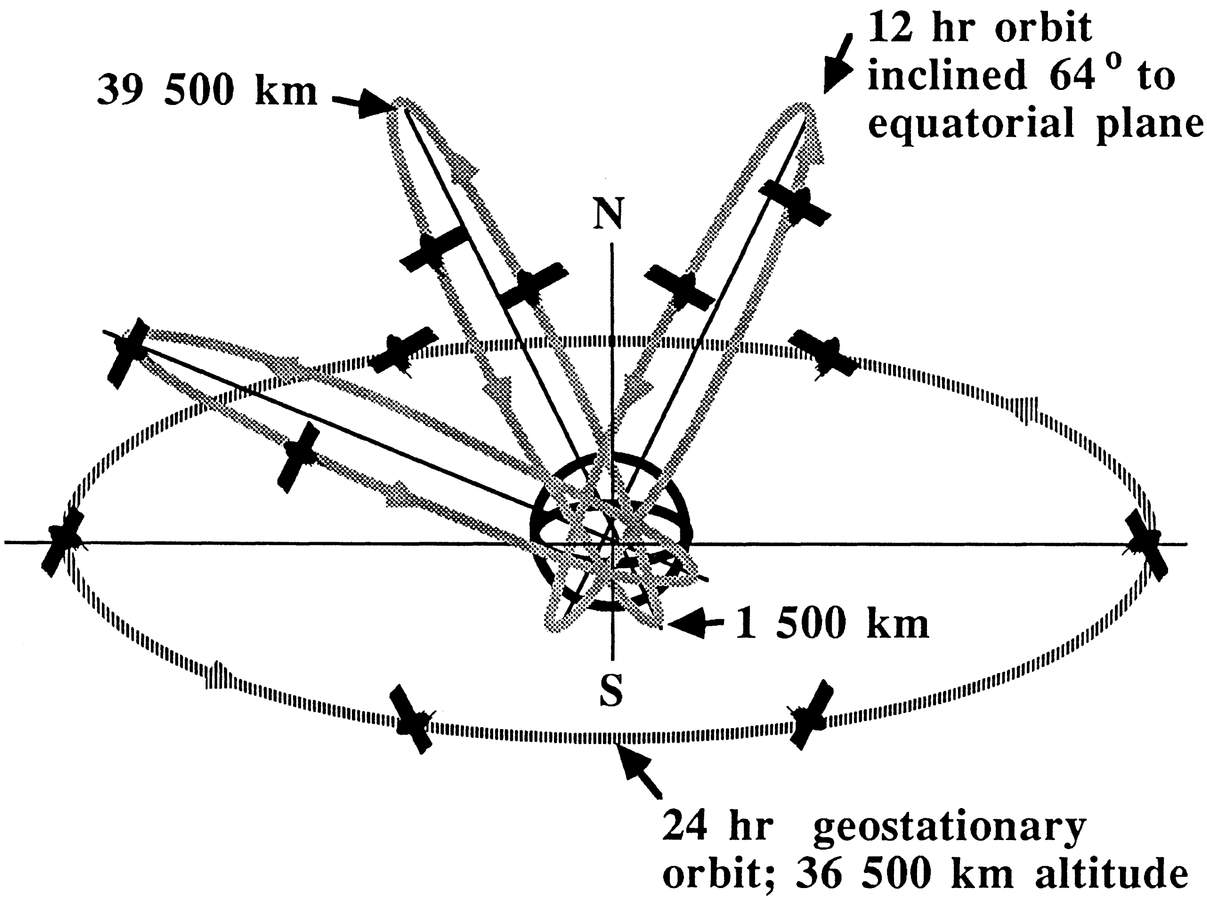
The U.S. Department of Defense has been pushing civilian use of their GPS system, probably for public relations reasons, and they have been pushing hard for the Federal Aviation Authority to specify it as a navigation system for aviation. But there is no way that it is going to be used for international aviation. Can you imagine Aeroflot landing in Moscow under the control of an American military navigation system? It will have to evolve quite a bit and be opened up before it gets used for commercial aviation. General aviation has a big market. There are many more general aviation aircraft than there are airlines.

NAVSAT was a very nice proposal. It solved a problem that GPS does not solve. GPS answers the question: Where am I? It is a navigation system. You track the signal and you can find out where you are. It does not answer the questions: Where are you? This is what you want for search and rescue and for tracking. For example, right now there are 190,000 railcars in Canada, and the railways would love to know where they all are. If they could find something for maybe even $100 that they could just slap on the cars and some satellite system could kept track of it, they would save lots and lots of money. They won't get it from GPS, because the railcar may know where it is, but that doesn't tell the railway. Whereas this NAVSAT had the added tracking capabilities so that the fixed monitor can get the information about where the user is as well as the user finding out where he is. So this answers both questions: Where am I? and Where are you? It had some advantages, but it doesn't look as though it is going to go.

The last system, GEOSTAR (see Figure 28), is one that answers only the question: Where are you? Well, not really, but it is a tracking system. This one is a commercial proposal from the U.S. It started off in left field as some physics professor from Princton and a lobbying Washington lawyer and the ex-administrator of NASA got together and made up this proposal and then got some funding. They actually developed a receiver. Their entry level receiver was $450 and it goes down from there. The low cost is because they put all the intelligence on the ground not in the satellite or in the receivers. They were going to just piggyback on communications satellites so that they could have satellites that were distributed above the equator at the geosynchronous altitude. As a result, it wouldn't be a great system for the arctic or near

FIGURE 27

NAVSAT

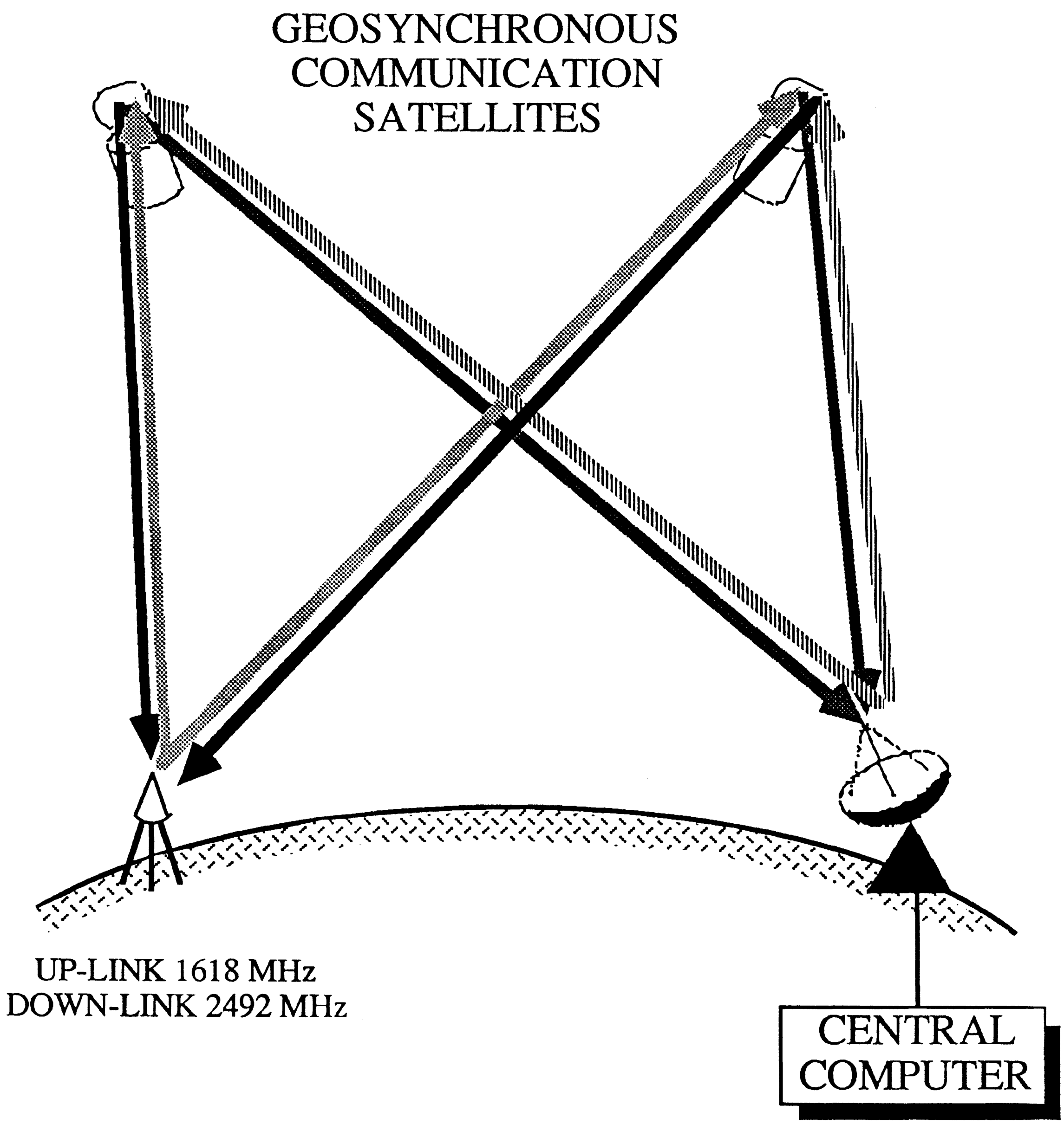


ORBITS

TYPE	i(°)	Ω(°)	ω(°)	# SATS	PHASES(°)
elliptic	63.4	0	270	2	180, 240
elliptic	63.4	120	270	2	168, 205.5
elliptic	63.4	240	270	2	154.5, 192
circular	0	0	0	6	0, 60, 120, 180, 240, 300

FIGURE 28

GEOSTAR



the poles, but it would be all right for the continental U.S. and perhaps for most of Canada. It was not going to have geodetic quality. They were talking about perhaps 1 m navigation. It may be that differentially some games could be played with little more expensive receivers.

What has happened with this is that they have the money, they said they wanted to be in operation by 1987, they expected to have 100,000 receivers in operation by 1990. They are the people who want to put these things on all the railway cars. However, they have to apply for permission to use the frequencies, and they have a lot of frequencies going between the satellites and the ground station, and the agency that approves these things in Washington said, well we're not too sure how to handle this. Let's go back and see if there is anyone else out there who wants to do the same thing. Of course, now there are, about 6 who want to do the same thing. So instead of this being some people with a bright idea, now they have to compete with 6 other people who want to do something similar. So it is likely going to delay them a little while. But this has been tested.

The last thing in the article here says they have gone into the western U.S. and put several of the packages they would put in the communications satellites on mountain peaks to pretend they are satellites to see how it works. They have published some results which seem to indicate it will do what they think it will. It may not have a whole lot of implications for control surveys because they are not designing it for that kind of use, but who knows, once it is up, and we start looking around at these $500 receivers, and maybe do some testing, we may get better than what they anticipate.

lunch

Dave Wells: (Slides - as there are no paper copies of these, only essential details have been left in.) Macrometer. Three racks for three modules in a heavy rack; they put minimum development into the hardware and a lot of time making the software easy to use; it is foolproof. They designed the electronics, specific to the Macrometer, very well indeed. It was not intended that this become a portable piece of equipment at that stage. (next) That is the handheld control module for the Macrometer; just press a couple of buttons. It has a number of commands. We thought it very easy to use in 1983. (next) The processing unit for the Macrometer is simply a PDP11 or LSI11 computer. Texas Instruments receiver. More portable; a lot smaller antenna; however, antenna probably does not have as stable a phase centre—more subject to multi-pass reflections off the ground—than the Macrometer antenna.

Earl Robinson: What is the price of that Dave?

Dave Wells: $140,000 U.S. If you want to record any data it is another $20,000. Any spares or options can built it up very easily to $200,000 U.S. per receiver.

(next) The original STI5001 cost more than anything else—1/4 of a million dollars for one receiver. Tracked only one satellite at a time; took a minute to switch between satellites. Nortech started with this in 1980 as it was all that was available until the TI came out in 1983.

(next) Magnavox T-set. Just a terminal with one circuit board contributed by Magnavox. An excellent kind of product, but Magnavox doesn't have enough proprietary equipment in there so they don't get enough profit. They want to build their own.

(next) Wild-Magnavox 101. At that point just an empty box; a fairly portable unit. (next) Wild-Magnavox 101 closer up. About the size of an attache case; very portable. Its battery supply will run it for some hours if not a day. It has all sorts of power starve circuits built in so nothing is turned on; the computer isn't turned on until there is enough data to compute the fix; records the data automatically just like the Magnavox 1502 Transit receiver. It will have fairly sophisticated software for navigation and geodetic positioning. The two cups are for modems so if you have a phone line you can have real-time transmission to another site or reception of correction signals from a monitor site. Price tag at present is about $90,000 U.S.

(next) Litton geodetic survey set. Reasonably portable, but just an empty box at present. They have an avionics receiver that this will be based on, but this will be at least a year away; no price on it yet.

(next) ISTAC 1991. The receiver is the small case, about the size of a book with microstrip antenna which caused difficulties; you also need a standard piece of test equipment. Everything worked OK except for that second white thing on the ground. They didn't design it, but bought it off the shelf; it needed 110 volts whereas theirs didn't. This was not a successful product. They've replaced it now with the announced 2002. No picture of that yet. The 2002 is supposed to be $57,000 with no options, and the specification of the 2002 is, they say, 30 cm in 3 minutes and 10 cm in 15 minutes. So it doesn't quite get down to your 5 cm. It might if you track for a longer period.

(next) Trimble 4000A. 130 sold this year. A 4-channel C/A-code single frequency code correlation receiver. Built-in position calculator for navigation; not of great benefit for geodetic positioning as it doesn't bring the phase measurements out. Its more recent clone, due Oct or Nov 1985, will do that. A lot of people waiting for the 4000S. It is not that portable.

(next) Japan Radio Corporation: A pack of cigarettes between the antenna and the receiver shows that it is not very big. That is $12,500.

Earl Robinson: Have you seen it working?

Dave Wells: We'll have to see what JMR has done with it. This is the receiver they have repackaged in an attache case, and called a geodetic receiver. No price tag; no accuracy figures so far.

Earl Robinson: Well what do these people say?

Dave Wells: These people are saying that it is a single channel navigation receiver. If JMR have done anything with it they will have had to bring the phase out. I don't know if the JRC design actually brought the phase out or not. Without the phase, it is a differential 5 metre system, 20 metres by itself, or maybe 10 metres once the orbit ephemeris is more accurately known.

Bill Robertson: Well it is the right size.

Dave Wells: (next) This shows where the GLONASS satellites were at a certain time on the first of May 1984, before the last 3 were launched. You can see how there are some arcs that are following each other along.

(next) GEOSTAR system. They want to put something on every truck in North America so that the fleet managers, either for taxis or trucks, will be able to tell where all the members of their fleet were at any time.

(next) European Space Agency NAVSAT scenario. They showed all kinds of potential users with varying accuracy, whether they wanted to track people or find out where they were themselves.

(next) The GPS satellites. That's all I have.

Murray Banks: Dave, what is the life expectency of a satellite?

Dave Wells: They say something like 6 or 7 years. But they said the same thing for the Transit satellites and one of those which was launched in 1977 was just recently turned off. They said each would last 5 or 6 years so they have 10 of them left they don't know what to do with. There is a difference however. The Transit satellites don't use up any fuel because they don't try and keep themselves in a particular orbit or a particular position relative to anything else. They just go wherever the gravity field takes them. Whereas the GPS satellites have to be kept equally spaced so they have what they call burns every now and then where they fire a little ion jet or something and that repositions them somewhere else along the orbital track. This keeps them equally spaced but when that exhausts itself, even though all the electronics may still be operating perfectly, the satellite starts drifting out of its assigned position, and it will have to be turned off. That may be the ultimate determination of the life expectency.

Murray Banks: Do you think the Spaceshuttle will retrieve them and bring them back to be refurbished?

Dave Wells: They are pretty far up. I don't know if they can just bring them down. They are starting the procurement process for the next generation of GPS satellites which will not be launched until 1995. They have actually begun work on those already. The first lot of production satellites is 28. They will launch 21 and have 7 spares for launch after that. They expect to have to start replacing that 28 in 1995.

Murray Banks: Are these satellites in such an orbit that they are not useful in Russia.

Dave Wells: Oh I think the idea is that they should be very useful in Russia in case the U.S. decides to send a fleet of supersonic bombers over Russia. They want to make sure that the GPS will get them there.

Murray Banks: I mean, can the Russians use these satellites for surveying or whatever?

Dave Wells: Yes, sure. It will have symmetric coverage all over the earth once all the satellites are up. In fact, over the summer we had a student looking at where there may be some weaknesses in coverage and there are little patches at latitude 35 and at latitude 68. Spaced about 20° longitude apart, there are just little diamond shaped areas where, during something of the order of a few minutes a day, the fix gets a little bit weak. But for surveying purposes it doesn't make any difference. That is just for navigation. So for something like up to 10 minutes a day, you might get a little worse than the specifications.

Murray Banks: Do you think the Russians are putting up their own system because they don't want to take a chance on using the American's?

Dave Wells: Yes, I think so. Again it is part of the armaments race. They want to understand the technology.

Richard Langley: The Russians have their own Transit system. That was a natural follow on or competition with the U.S. Transit system. GLONASS is competition with the U.S. GPS system.

Dave Wells: I have some brochures here. They are not extras, but I can pass them around if you want to have a look at these things in a little more detail. There are a couple here I haven't mentioned. There is a company in Hannover, West Germany, Trackless Seismos, that is developing a GPS receiver. It doesn't look anything like this picture yet, but it fills most of the back of a truck right now. And there is a company in the U.K. called Pollytechnik that has had a GPS receiver around for about 18 months. I think it was $50,000. It is a C/A-code single channel receiver. We can make copies of these later if you want.

Earl Robinson: So in 5 years time am I going to be able to buy one of these survey ones for $40,000?

Dave Wells: I think you should be able to buy something within a year. You won't have something backpackable for $40,000 Canadian giving you 5 cm within a year. But if you wanted to relax any one of those 3, if you wanted to go up to $60,000, or if you wanted to go up to 20 cm, or if you wanted to go up a little higher in weight, then there will be something available. The Trimble coming out the fall of '85 should give you the 5 cm but it won't be backpackable. It is supposed to be about $40,000 U.S. It is $25,000 without the phase option. They haven't actually given a firm price on it with the phase option, but the rumour is it would go up about $10,000 to $15,000. The ISTAC 2002 costs $57,000; it is backpackable (about the size of a book). It may in fact give you the 5 cm if you sit there for long enough; longer than the 15 minutes they recommend.

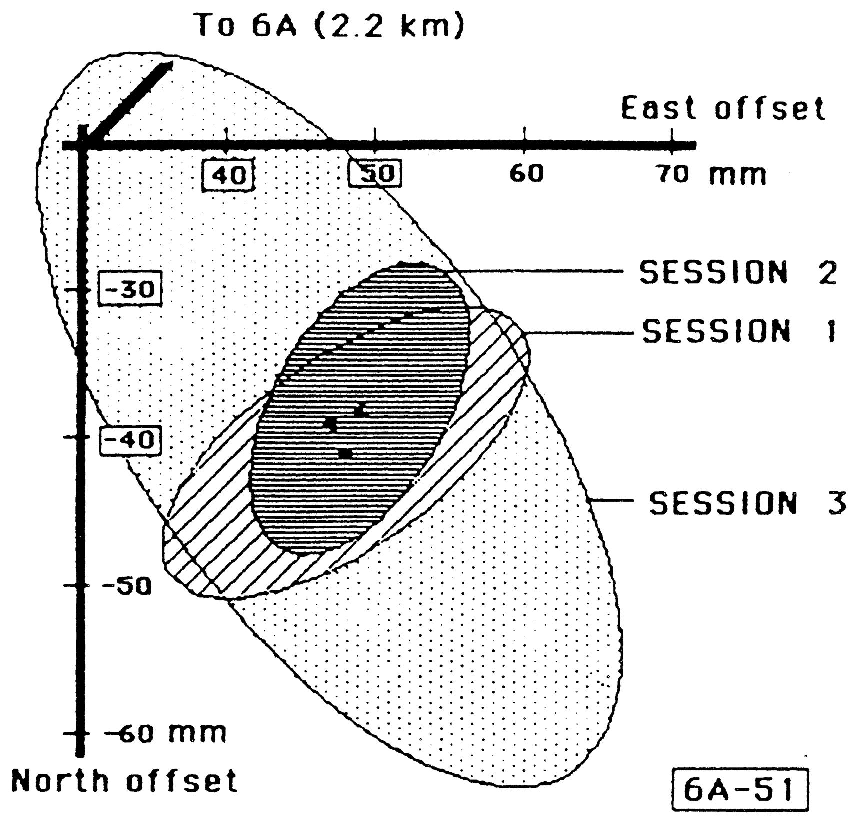
Earl Robinson: The times in this article are all based on all 18 satellites being up?

Dave Wells: No. What you do now is that you have a window of about 5 hours where you get coverage that is approximate. It is not quite as good as it will be when the 18 are all up, but it is adequate enough to do reasonable work. Even in that window, it will improve somewhat once all the satellites are up. That is the way the system has been used. At present, you find out when the 5-hour window is each day, it changes by 4 minutes a day, and you go out and do all your surveying for the day between 2 a.m. and 7 a.m., or whatever.

Earl Robinson: So the difference between 7 and 18 satellites widens the window?

Dave Wells: It also improves the geometry even during the 5-hour window but we can get reasonable results with even that. I have a couple of sample results that might be worth putting up just to show.

Figure 29 is a kilometre baseline. What I am showing here is one end of the baseline, location 6A, which is held fixed. We are seeing how the free end of the baseline flops around when we measure the baseline vector using GPS with 2 receivers. This was done with 2 Macrometers in 1983 when only 4 satellites were available, not 6 as there are now. We set up the receivers for 3 sessions of one hour each all on the same day. We had this 5-hour window and we chopped it into 3 observing sessions. We got three separate solutions. These are the 95% confidence regions in latitude and longitude for each of the three solutions, and the solutions themselves are here. These scales are in millimetres with respect to the ground reference, so we are offset by 50 mm in longitude and 40 mm in latitude. We haven't done anything to adjust the coordinate systems, and we think there is a rotation between the terrestrial and the satellite coordinates that would reduce that. This is on the National Geodetic Baseline in Ottawa, so it is



MACROMETER V-1000 RESULTS
6A TO 51 (2.2 KM)
NOTE: 2 MM = 1 PPM

FIGURE 29

Stations 6A and 51, which are 2 stations on that baseline. We see that the length was determined pretty well, but there is a rotation. This little stub points the direction toward the other station on the baseline, so we have about the same length but with some kind of a rotation. You can see we are at the millimetre level at about 2 km with a single frequency squaring type receiver like the Macrometer.

Figure 30 shows a little bit longer baseline; this one is 20 km. Again these are three different sessions but these are 3, 5-hour sessions. Unfortunately we haven't looked at breaking those up into smaller lots to see how they would compare. The scale is a little different here. We have 5 cm between these points but we can see that they seem to be repeatable within 5 cm. So we can give you your 5 cm now, but you are going to have to carry an awful lot of weight around and pay a lot of money if you use a Macrometer. There is no reason to believe that the Trimble won't be able to give us exactly what we can get from the Macrometer and TI at the present time, once they have this phase out. I think it will take 6 months of testing before we can confirm that they have done something stupid or wrong in their design.

Earl Robinson: What I am trying to get is some idea of the time. Someone said it will be more than 25 years before this is going to become feasible. Based on what you have said, and on what we have seen, the size is now reduced, the price has gone down to half on the new systems. Is that going to continue? In 5 years' time are we going to be doing the same thing with GPS that we do with EDMs now? Is everyone going to have one?

Dave Wells: I don't think everyone is going to have one in 5 years' time, but I think it will be possible for forward looking, enterprising surveyors to get into the GPS game in a big way. There are several companies in Canada that are using GPS for a lot of things. This Alberta contract with Usher and Associates, for example, has been running for 2 years now so they have a fair amount of GPS experience. They will want to capitalize on that, but they haven't purchased any equipment. They lease Macrometers for the period of the contract and that's it. They are not down to $600 per control point. They are paying $3,000 a control point because they are going out and recovering target corners that were originally surveyed in 1909 and two-thirds of which have not been revisited since. So there is a lot of bush to be cleared, a lot of forest to be cut, and everything has to be done in helicopters because the receiver is so heavy. For last year's survey they started the end of August and finished the end of October. They started at +30°C and ended at -32°C with 10 m of snow on the ground. But they got all the points done to their specifications.

Earl Robinson: I see some American companies advertising GPS at $500 a point.

Dave Wells: Yes, that is the Macrometer lease rate. That is their cost but there is no manpower there. The Usher and Associates' cost included the helicopter, the 37-man crew, the bush clearing, and the relocation and finding of everything.

Earl Robinson: Well, from these advertisements, I concluded these people would come in and could put points in for you at $500 a point.

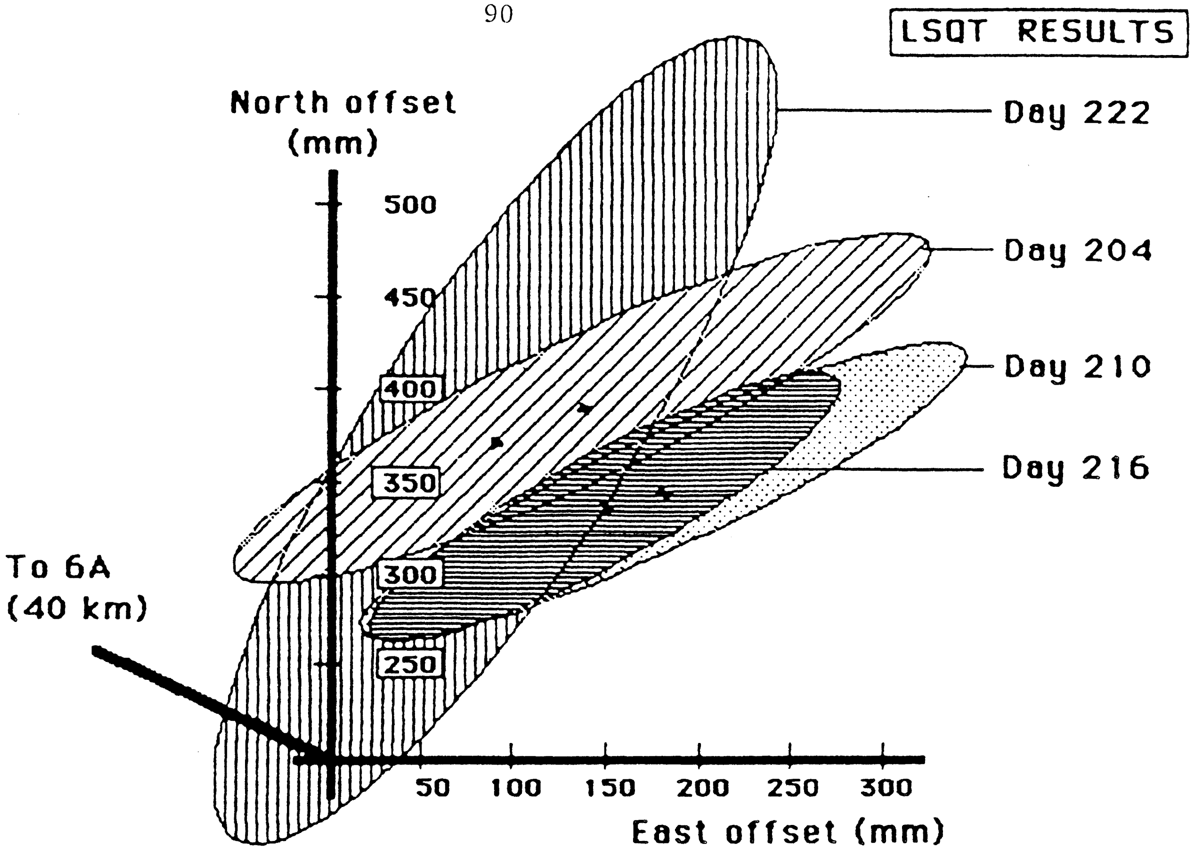
Dave Wells: That's Geo/Hydro and if you read the fine print they have three prices. They have $500, $1,000 and $2,000 a point and that depends on whether you want fourth order, third order, or whatever. That means they can observe for less than an hour to get $500 accuracy and maybe 3 hours to get $2,000 accuracy. So there is a certain level they are tuning themselves to.

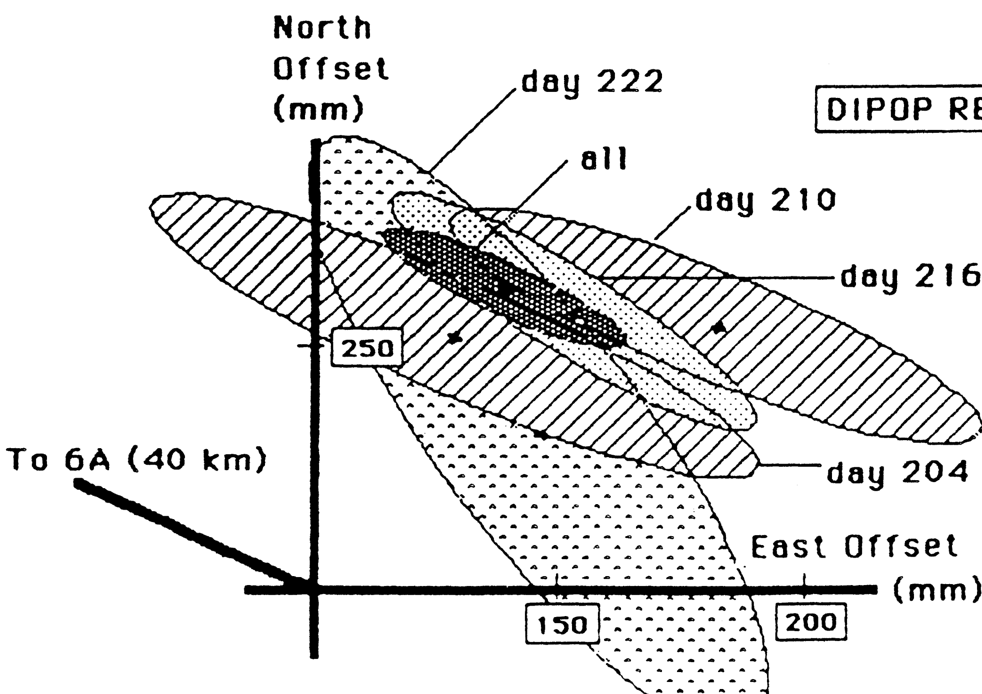
Murray Banks: In N.S. Crown lands, we have about 30,000 monuments or 10,000 miles of boundary line and a lot of these lines in dense forest. I was reading some literature, and it seems to me you would have to have 15° line of sight from the horizontal. So I can visualise that clearing big swaths of forest would be bit of a problem for us.

Earl Robinson: You could build a tower.

Dave Wells: The antenna could be raised on a pole of some sort as long as you met the accuracies.

Murray Banks: I was just wondering if there was some way around that.





MACROMETER V-1000 RESULTS

6A TO METCALFE (40 KM)

NOTE: 40 MM = 1 PPM

FIGURE 30

Dave Wells: They had the same problem using Transit in Indonesia, in the jungles in Borneo. Most of the islands in Indonesia have not been tied together and McElhaney in Vancouver got a contract about 10 years ago to tie them together. They put in 200 or 300 control points on a lot of these islands—probably more than that—and they found there was just so much jungle cutting it was costing them too much. So they developed this technique of putting the antenna on the top of a very long pole and using some accurate plumbing techniques so that they knew where it was with respect to the monument. That saved them a lot.

Murray Banks: I am sure there is some way around it, we just have to figure out what it is.

Dave Wells: There is one Canadian receiver that is based on the Japan Radio Corp. one that JMR is building, and Nortech is building something called the NORSTAR 1000. Here is an article from the *Globe and Mail* that talks about that. It is primarily intended as a navigation receiver, but I want to stress again that any navigation receiver that has sufficiently well designed circuits and brings the phase measurements out can be used just as easily for a geodetic receiver.

The fellow that Richard mentioned as being the Canadian who won the race to first demonstrate the feasibility of very long baseline interferometry, Allan Yen at the University of Toronto, has been designing a GPS receiver of novel design for the Earth Physics Branch. We still haven't heard whether or not it has been successfully demonstrated, but if it does turn out to be successful, that would be a very major candidate to compete with things like Macrometer and the Jet Propulsion Lab designs and provide a lot of information depending on how it is marketed and who gets the license to manufacture it. It could be quite a competitive machine.

There is a little company in Ottawa called Starnav founded by a UNB graduate, Mike Dyment, who has some ideas about how to use GPS not only for positioning but for orientation as well using a pair of antennas and short baseline interferometry—comparing the signals from two antennas inside one receiver. He makes noises about having a receiver available fairly soon.

Canadian Marconi, who did build Transit receivers for a while, have had some military contracts to develop GPS receivers. They have delivered some receivers eventually, a little bit late but still delivered, for helicopter navigation to both the Canadian Armed Forces and the Italian Armed Forces. We are putting together a receiver at UNB in the Electrical Engineering Department as a student project.

Mary Ogilvie: Is the cost of satellites coming down too?

Dave Wells: They keep putting more stuff in these satellites. In terms of launching our own satellites you mean? To launch a system to compete with the GPS would be a major undertaking, I mean billions of dollars. You can't have coverage just for Canada unless you have geostationary orbits and then the geometry is not very good. You have to have some kind of orbital configuration that if you want to have 24 hour coverage you are going to have to have global coverage so we would be donating a system to the world, as the U.S. military has done. It would at least double our national debt. I would think that if there was support in Canada for a civilian navigation system along the lines of GPS, the best bet would be to somehow lend our support as a nation to the European Space Agency proposal for NAVSAT. To me, that was an excellent proposal. It had a lot of very well thought out ideas, but it was developed by people who had ideas but no money. They have been peddling it now for 5 or 6 years and nobody has picked it up, so it won't happen.

Angus Hamilton: Any more questions for Dave? We have drifted into the workshop discussion. Yesterday I made a list of questions to stimulate discussion. Quite a few of these we have already discussed, but I thought we would just go through them to crystalise our thoughts on where we are today.

Dave Wells: We should talk about inertial first.

Adam Chrzanowski: Well, to talk about inertial now will be like eating horseradish mustard after dinner. I will say just a few words about new developments in inertial surveys as reported at the last international symposium in Banff a month ago. Instead of going through all the principles of inertial, which will be of less interest, there are a few reports that indicate that inertial surveys may reach accuracies of a few centimetres, relative accuracies, over distances ranging up to say 50 km.

It is a system (viewgraph) which perhaps could compete in the future with other technologies. As far as accuracy is concerned, I don't think it could compete with GPS, but certainly it may compete as far as the speed is concerned. This is because, in inertial surveys, we have the continuous updating of the positions of a moving vehicle on which the inertial system is mounted. There are proposals to produce a hybrid system like tying the GPS receiver together with the inertial system so that when the GPS receiver would lose lock, because of shading of the antenna during the travel, it would be updated through the inertial system. Inertial in this case would be like a system which would update the phase measurements of the GPS system. It is one idea which I think would be quite a good combination.

The main problem with the inertial system is the price. It is still about one million dollars for just one system mounted either in a vehicle or on a helicopter. This price probably won't go down, because the components of the system are very expensive, particularly the gyros which must control the stability of the platform with respect to the space coordinate system. There is a development coming in the gyros, that is, the use of laser gyros, which wouldn't have any mechanical moving components. This could decrease the price of the system by tying the platform to the vehicle. To explain this, we have to go through the very basic principle of the inertial system.

In the inertial system we must measure accelerations of a platform mounted on a vehicle. If we know the acceleration, we can calculate the distance travelled by the vehicle by double integration of acceleration. If we measure three components of acceleration, in three perpendicular directions, we can calculate the total distance travelled or we can calculate differences in coordinates. The present systems use the platforms which are space fixed. It means that the gyros, which are mounted on the platform, maintain the orientation of the platform in the same space direction as at the initial point from which the vehicle starts travelling. In other systems, we maintain the orientation but we change the position of the platform according to the local gravity vector. So it is continuously updating the position of the platform with respect to the horizon.

There is a third possibility: To tie the system, to strap it down, to the vehicle. The platform wouldn't have to have any precision gimbal system on which it would move with respect to the vehicle, and the gyros in the system would give continuously updated information on the change in the relative position of the platform with respect to its initial orientation at the initial point. This sytem would be much cheaper than the other one because of the simplicity of the mechanical components. The platform would be mounted fixed to the vehicle while in the other two systems, it has to have a very precise gimbal system on which it can move with respect to the vehicle to maintain the space orientation. With the presently used gyros this is impossible, because the gyros themselves have mechanical components and they don't instantaneously respond to sudden changes in the directions. Due to frictions in the mechanical bearings, the gyros show a drift in time which produces errors in position which are proportional to the cubic of time travelled between the points. With the development of new laser gyros, as I mentioned—ring lasers or laser gyros—it become feasible to use this system. Then the price of the system could come down by maybe a factor of three. Still it would be very expensive, about $300,000.

Right now we have three basic manufacturers of inertial systems. **Litton** came into the market first in 1967 for military purposes and 1975 produced the first surveying system. **Ferranti** in England and **Honeywell**, the youngest producer of the survey systems, is in the U.S. With Litton we have an inertial positioning system for rapid geodetic surveys which is used by the Geodetic Survey of Canada. Ferranti is used by companies like Nortech which has the system Fills 2, Ferranti survey system Mark 1 or Mark 2 which has been extensively used in different countries. Honeywell produces Geospin 2. All the systems are similar in the basic principle. The differences are mainly in the software for the calculation of the positions from the measured accelerations and in modelling of the errors involved in the inertial systems.

Just last year, a German company in Bockum produced a prototype of a strapdown system using not a laser gyro but a rotor gyro. It is for mining applications. It is an application where GPS would be unable to compete as we cannot get satellite signals underground. So, for mining applications, this system would be used for monitoring the deformations of deep mining shafts with continuous travelling of the inertial platform attached to the elevator in the shaft. So this is a strapdown system. The main differences between the systems are in the kinds of gyros being used, but I won't go into details.

As for the errors in the inertial navigation systems: we have errors in accelerometers such as scale error, gyro drift which is smaller in the Honeywell systems because they use electrostatically suspended gyros which have fewer moving mechanical components. Some of these errors are removed by updating the zero velocity. This means that the system has to stop every few minutes and compare the velocities recorded by the accelerometers with the zero velocity, which we know is zero because we stopped the vehicle. Some of the drift errors are removed and can be modelled using Kalman filtering, modelled and predicted even for the further travelling, and partially removed. But still a lot of systematic errors remain in this sytem. This updating is called zupt—zero velocity updating. Apparently the shorter the time interval between zupt stops the better the accuracy. Recently, Nortech Surveys used 2 minute intervals. So even when using this on a helicopter, we have to land every 2 minutes to update the velocity. It takes about 30 seconds, but still we have to stop, then go again. With 2 minute intervals they are claiming accuracy below 5 cm in relative positioning. On the lines, say not exceeding total travel time of 2 to 2 1/2 hours with the zupts every 2 to 3 minutes. Here, the accuracies (1983) from many surveys gave, on average, for latitude 19 cm plus about 3 ppm of the travel distance, and for longitude, 60 cm and 6 ppm.

The inertial system can also measure the deflections of the vertical with an accuracy of about 1 second of arc and irregularities in the gravity field with an accuracy of 2 milligals. Nortech published very interesting results of their surveys with the Ferranti system in Australia (viewgraph). In their surveys a very interesting thing was the cost analysis. Everybody was talking about the inertial surveys that due to the speed of the measurement we get the coordinates almost continuously when travelling with the system then we can get the coordinates of many points per day. Apparently they did some small projects like an area of 27 x 36 km to establish 9 new points for photo control for 1:10,000 mapping with 9 existing control points in the area. It took them 2 days with the helicopter to do the job including reconnaissance preparation. They realized that the cost of the operation was 20% higher than using conventional terrestrial surveys. They got the coordinates much faster, but the total cost was higher because of the high cost of the equipment. Probably these 9 points would take 2 weeks of conventional surveys depending on the topography and visibility.

Test surveys in the city of Adelaide, 27 points at 700 m intervals, were established with the Ferranti system. They got 10 cm, 14 cm, and 30 cm standard errors of the determinations of the x, y, z positions. In a photogrammetric test area near Brisbane, 3 km by 2 km, they used double run of each line with zupt every 2 minutes, and they obtained standard deviations of 4.6, 4.4, and 2.1 cm. So here we are getting below 5 cm accuracies using zupt every 2 minutes, double run of every line. But the cost analysis for the establishment of 50 control points cost of inertial system versus photogrammetric determination for the block adjustment for photoscale of 1 part in 3400, the cost was the same. There are more optimistic reports, for instance, by Reiger from Australia, who used the Litton system. He used 3 1/2 minute zupt intervals. The city environment with 750 m spacing between the stations. He obtained positioning accuracy of 37 mm, and in heights, 8 mm. In Germany, at the Bundeswehr University, they used 3 systems: Honeywell Geospin, Litton, and Ferranti. They used them on a test network of 8 traverses and 3 loops in an area of 30 km by 15 km. 70 stations with a 2 km separation; accuracies achieved better than 5 cm for positioning. For gravity observations, 1/10 of a milligal, and deflections of the vertical better than 1 second of arc. So there is the potential as far as accuracy is concerned, but it costs a lot of money. I believe that a combination with GPS used in a continuous mode of operation as mentioned earlier could be useful with the updating of the GPS input by the inertial system if the antenna should be shaded or won't receive the signals. This is possibly the future for a dynamic system to operate continuously along highways.

Dave Wells: Except in that case you wouldn't have to have anywhere near the kind of precise system you have here. You wouldn't need a million dollar system for that. You could perhaps get away with a system that was much much less expensive. Just to aid the retention of the phase tracking of the GPS receiver.

Adam Chrzanowski: Perhaps yes, if the only purpose of the inertial system would be just to update the GPS signal.

Dave Wells: Klaus-Peter Schwarz has done a comparison of this for aircraft where you have GPS as a major system and could put an inertial system in there just so that when you have some kind of shading or the aircraft lean somehow shades the antenna from the satellites that you still have a continuous phase reckoning. He looked at having an expensive inertial system with GPS aiding it or a GPS system with an inexpensive inertial system aiding the GPS. He found the second one first of all gave him better results in a simulation and secondly cost an awful lot less.

Mary Ogilvie: Dave, is it inertial systems that they use on board ship?

Dave Wells: Were you thinking of Mike Eaton's trials?

Mary Ogilvie: No, way back in the '70s when I was on board ship and they had the inertial system in the bowels of the ship and we were using it with Loran-C.

Dave Wells: What would be on the ship then would have been a gyrocompass but not an inertial system.

Adam Chrzanowski: All the commercial airliners use inertial systems for navigation.

Dave Wells: Yes, but not million dollar ones. More like $100,000 ones.

Adam Chrzanowski: Right, they don't need these accuracies.

Murray Banks: Dave, Geodetic Survey of Canada say they have done some work with GPS. Normally they would occupy some of their existing stations just to do some comparisons, like when they come up with the absolute position of a geodetic station in a fairly strong network. What kind of discrepancies were they finding between that and what they had from conventional ground surveys?

Dave Wells: That was what I was showing in those error ellipse diagrams. The problem is that even a strong conventional network is unlikely to be better than GPS so you can't use it as a standard to judge GPS. We have to assume there will be some differences in the coordinate systems. We have to be prepared to apply some kind of rotation and scale change to allow that to absorb some of the differences and then see what there is. When we do that we are down in the centimetre region. But I think that probably the best job that has been done of producing a conventional network for testing GPS was done in Switzerland. There is a nuclear accelerator near Geneva and they are building a new underground accelerator that is going to have a circumference of 27 km. It has to be precisely lined up to the millimetre or subcentimetre level. The first thing they did with their survey division was they went in and used a Terameter, a two colour laser EDM. They made a very dense gravity field measurement so they could calculate the changes in the deflection of the vertical over the smaller area they had here. They ended up with a three-dimensional network that they estimated was good to 1.5 mm over the 10 by 10 km area; good to about 1.5 mm horizontally and 2 mm vertically, relatively, over that area. This took them a couple of years to do all the pillars which had insulation around them, etc. A very dramatic demonstration of this thing. They went in with a Macrometer for three days and occupied all the points. They computed the GPS coordinates and compared them after a coordinate system transformation with what they had done with the terrestrial stuff, and they agreed to better than 1 mm.

Murray Banks: What I was coming at, since you get the absolute position of a point using GPS, and the conventional terrain systems let you do some balancing throughout your network somewhat so you get pretty good relative comparisons between stations but you are out in some of the remote areas, like Labrador, where your balancing is getting your system a little weaker, all of a sudden you go in and take an absolute position with GPS and you might find quite a discrepancy.

Dave Wells: First of all, the way we use GPS to get the highest accuracies is in a relative mode. We use two or more receivers. So it is again like a fancy three-dimensional EDM.

Murray Banks: Oh, I didn't realize that.

Dave Wells: Yes, we can get absolute but what is absolute. Absolute with respect to somebody's coordinate system.

Bill Robertson: Somebody's model of the earth or something?

Dave Wells: Yes. That comes through the satellite ephemeri and all sorts of things. But it gets pretty well lost so we would anticipate that the absolute coordinates if we have just one receiver are going to wander around by, say, 10 metres. But when we use two receivers at once, we can cancel a whole lot of stuff and that is when we get down to millimetres and centimetres.

Bill Robertson: For this geodetic array we are talking about Dave, do you have one receiver at one end of the line and another at the other end?

Dave Wells: They are talking about having 20 receivers, one for each area.

Bill Robertson: But each individual would only have to have one?

Dave Wells: Yes, that is one way of using it. But, for example, let's look at the LRIS problem again. Somebody mentioned that you want to put them in in pairs at least so you have an azimuth line. That would mean that a minimum system that would be useful would be to have one central receiver that could be in Moncton or Fredericton, or wherever, or one per province, and then perhaps have survey teams with pairs of receivers. What you get is the two receivers, maybe a couple of hundred kilometres away from the base station, and under those circumstances you might expect a decimetre relative positioning. But if you put the two of them up and track at the same time, and they are only a few hundred metres apart, then you should be down to the millimetre region, or a few millimetres region, for the pair of stations. So if you take those and put them in every couple of kilometres, or whatever density is decided on. That would be one scenario.

Bill Robertson: Suppose we had the central one in Moncton and we put in two monuments. We occupied one and determine it relative to this point in the middle. Put that same instrument down and occupy the second one ...

Dave Wells: They will each have an independent uncertainty with respect to the Moncton station at the decimetre level and therefore they may be decimetres apart. The uncertainty between the two may be decimetres as well. You really have to track the same signals at the same time from the same satellites to get the best cancellation of all the errors and biases.

Adam Chrzanowski: It means we will still have to maintain a certain number of control points in order to get the reference from them for GPS positioning.

Dave Wells: I think we can look at a heirarchy. It seems to me that, as Richard mentioned, the absolute system, or the system that is most likely to be the zeroth order, maybe the zero zero order or something, is likely to be the VLBI and there may only be a few stations per continent or country. We densify between the VLBI with something like GPS. This is one scenario that the Geodetic Survey of Canada is looking at that seems to have some problems, in that we have a number of permanent GPS monitoring stations that provide the differential corrections to the ordinary user which in the first instance may be an organization like LRIS. Possibly once the cost of the equipment is down and it is competing with conventional survey equipment, every survey company or organization may end up that way. There is an awful lot of ifs along the road. These are all still predictions.

Murray Banks: I see quite a few political implications here. In N.S. alone, we have spent 10 million dollars just to put 21,873 monuments in the ground. We don't want them to become obsolete overnight. We would have to do it pretty gradually. If you go to the politicians for money to buy equipment and tell them that this new thing has come along and we don't need these monuments anymore, we've got problems.

Dave Wells: No, you can't jump into anything like that overnight because you haven't got the replacement in place. The time that the replacement would be in place would be the time that every surveyor owns a GPS receiver. I don't think that is going to happen overnight.

Mary Ogilvie: That GPS stuff will only be useful, too, if there are coordinate values for them comparable to what their measurements are. Until you have coordinate values as a replacement for evidence as your boundary corners, GPS won't do you any good for your land surveying. In order to get that replacement for evidence, you have to have that control system of monuments and if that was temporary, so be it.

Wolfgang Faig: You have to be able to transform from one system to another. The property system may not be in the spatial GPS system.

Dave Wells: I think the main thing is that you may be able to have a less dense monumented control system. You wouldn't have to have intervisibility between all of the sites to maintain it, as I understand is the problem right now.

Murray Banks: We are asking for more money each year to maintain our present system. What we have to try to decide, and I hope it will come out of this workshop and subsequent studies, is just where are we going. Do we stop asking for all this money for maintenance and start gearing our train of thought to GPS.

Dave Wells: I can see that as a sort of midway thing. You somehow try to find a way of using something like GPS, if it is possible, to reduce the cost of maintenance. I think some studies are necessary to show whether or not that is in fact the case. In other words, you somehow find ways of using GPS purely as a maintenance tool at the present time but it means it gets you into the technology and gives you experience and you start to build up the infrastructure that would be required if eventually the survey community adopts it as a major tool. This seems to be a very useful possible entry scenario. You look at the cost of maintenance and see if in fact there are ways. It is not going to happen next year, but I can see perhaps by 1990 there may be possiblities with the full coverage, the 24 hour a day coverage with the satellites, of being able to cut down on the maintenance costs. There will be some initial capital costs for a few receivers, but those are going to be coming down in price too. Maybe you can get three or four receivers for $100,000 by 1990.

Adam Chrzanowski: It would be time now to start deciding which monuments should stay for sure, even if GPS should come, and which monuments you could afford to lose. Like start designing our network of the controls with the point of view of the future adaptation to the use of GPS. Perhaps you don't have to replace all the monuments you are losing right now if you decide now that in the future, say, in 5 years, you go into GPS.

Murray Banks: The second component here is that we are not only concerned with maintenance but we are also concerned with densification which go hand in hand. If you have new development, like forestry access roads which are being built all over N.S., we are talking of moving the network out into these areas and so we have to think of that too. Do we continue to spend $600 a monument to set these things out, or do we slow down a bit because this thing seems to be evolving very quickly. It was only in 1978 or 79 that I first heard you talking about GPS, Dave, and look where we are right now.

Dave Wells: In terms of phasing down the density, or whatever ends up being the new procedure for the control network, there are probably steps that would be required. One of them would be, even though there may not be a GPS capability for the next few years, if there is a case where there are, say, 10 monuments along a 1 km stretch of road and that road is rebuilt and they are all destroyed, that you put 2 back in or something like that. The thing is to have some strategy whereby the density would meet the needs of the users of the control rather than the needs of the network, e.g., those cases where there are 10 monuments in a kilometre because of an intervisibility problem along that kilometre road.

Murray Banks: That is part of it and the rest is the specification that LRIS had for setting them too.

John McLaughlin: I gather though from Bill's discussion that you are already using that strategy in remonumentation now. You are putting in three rather than 10 to meet the user requirements rather than the original geometry.

Adam Chrzanowski: But do you still keep the policy that whenever you notice that the monument is destroyed that you try to put it back whether there is any need for this monument or not?

Murray Banks: Bill, you should answer that. I think you said this morning that you don't put it back if it isn't needed.

Bill Robertson: We don't put it back. If the monument is in a good location and what we perceive is a useful location, then it will probably be replaced. We would wait until there was a survey going on in that area and then take the time to put it in. The ones that aren't replaced are the ones that are not in good locations to start with. But the thing we have to be careful of is when you get into GPS how is it going to arrive? Is LRIS or the government going to get into it in the year one and then in year 10 the survey professions move into it, or are both the government and the survey people going to move into it at the same time? Because the real users of the coordinate systems are the land surveyors. They need the monuments when they are doing their surveys unless they are doing a GPS survey.

Dave Wells: I think that is the point. It may be that there is a use for GPS that meets an LRIS need of providing the maintenance and densification and control that may aleviate your budgetary problems. We have to look and see if in fact that is the case, but I think that would be one possibility. It would mean that there would be no commitment there that GPS is anything more than just a survey instrument for the maintenance and densification of the control network. Presumably, it wouldn't be useful to do that unless it could be shown to be more cost effective than the present technique. If the present trends with GPS continue, and it does become inexpensive enough and useful enough that it is adopted wholesale by the survey community, then LRIS would be very well positioned to capitalize on it, having become accustomed to the technology. But if it doesn't happen, it is still a useful tool from the point of view of the maintenance problem.

Wolfgang Faig: Until it happens, you still have to have your geodetic control network to bring position close to the user, and if you have new developments in forestry you have to open that up and you have to take control in there. Whether you take it in with GPS or another system is a different question. You have to get the control in there so the densification will be with you for a while.

Richard Langley: Getting the control in there you might need fewer points.

Wolfgang Faig: You might be able to position a pulp mill in the middle of nowhere without having to being the control all the way in.

Adam Chrzanowski: So it could mean that it is cheaper for LRIS just to provide GPS in bringing the control to the actual project rather than maintaining the existing geodetic control. You might need more survey crews with GPS receivers at least at the first stage. Later on perhaps some major land surveyors will buy their own equipment to do the surveys also for smaller companies.

Bill Robertson: The problem we are already facing is that there are firms out there now who are coming to us saying we are ready to provide you with GPS services and asking us if we want them.

Adam Chrzanowski: That is fine as long as they give a good price. Competition. Whoever gives the better price will be the winner.

Bill Robertson: My concern is that they know what they are talking about and we don't.

Mary Ogilvie: I don't think we have to invest $100,000 in equipment to find out what we are talking about.

Murray Banks: Bill mentioned a while ago that land surveyors were the users but I feel that the mappers, I separate them from surveyors and maybe you don't, are big users. All the maps that LRIS and EMR in Ottawa are producing, are all controlled by either the control monuments or traverses off the monuments. So I think we are going to need a network of control physically on the ground for many years to come because I don't think photogrammetry is having as much of a revolution.

Dave Wells: There is a project right now looking at aerotriangulation without control using GPS in the aircraft.

Murray Banks: I wondered if there was anything going on. As I see it right now you still have to control your models on the ground with a certain number of points.

Wolfgang Faig: You can carry an awful lot of control with photogrammetry.

Mary Ogilvie: Are there many people in Canada concerned about the U.S. tinkering around with the GPS system?

Dave Wells: If we have our own tracking network, which is what these active control points would in essence be, we would establish some of them as more or less known or fixed points; perhaps the ones that have radiotelescopes on them. Then we would establish a very close tie between them and other ones and they would all then become a basic tracking network. Then we are rather impervious to anything that the U.S. would do with the ephemeris or most of what they would do with the signals. As long as the U.S. DoD continues to broadcast something.

John McLaughlin: As long as they maintain the satellites.

Dave Wells: Yes, as long as they maintain the satellites or as long as the Russians don't shoot the satellites down. The way these codeless techniques work is that they track this thing assuming very little about what is coming down from the satellite. We could establish our own ephemeri that may not be very useful in Australia but it would be very useful at least in the northern half of North America. With the appropriate signal tracking techniques, such as the squaring mode and so on, and using differential positioning so that anything that happens to the signal in a timing sense happens at both receivers and therefore gets cancelled out when we difference the observations. Then what we are really worried about is will there be any satellites at all. Will there be any signals at all.

Murray Banks: I'm not quite as concerned after you say the price might come down to $500 a set but I would be quite concerned if we spent a quarter of a million dollars and the next day they shut them off.

Dave Wells: Let me say, everybody who is buying a set at the present time is taking that risk because there is actually an item that has appeared in the federal register from the Secretary of Defense saying: "Don't trust these signals: this is not an operational system, it is under development and we reserve the right to do anything at all to the signals including shutting them off." So anybody who goes out and buys a set right now, and there are a lot of people doing that and making money at it, is taking that risk.

Wolfgang Faig: If there are so many users in the U. S., they cannot afford to shut it down any more.

Dave Wells: I think the Department of Defense could, if they had a real reason to do it. They are bigger than the survey industry.

Richard Langley: If the FAA gets on board with GPS, they will have enough clout with the President and the U.S. Cabinet and I would think only in a dire emergency, such as an imminent war, would you expect the signals to be shut off.

Dave Wells: Yes, but we are talking about depending on this military system for our survey coordinate system. If it becomes generally used for a precise landing system, they won't click it off as some plane is coming in blind. FAA may come on board but ICAO is very much more reticent to get into it because of the international implications.

Mary Ogilvie: So they are unlikely to let planes fly with that as their only navigation tool?

Dave Wells: I think it would always have to be complemented with something. But it has a lot of advantages over inertial. After the Korean Airline disaster, there was a lot of pressure in the U.S. Congress to speed up the GPS system and get FAA approveal to install it in American airliners, because if it had been on board the Korean flight it would have indicated something was wrong with the inertial.

John McLaughlin: Yes, if that was the real problem.

Richard Langley: The Omega navigation system is another quasi-military U.S. system, and many international airlines use Omega for navigation.

Dave Wells: It is one of the things that you have on your list as being shut down. However, in the Federal Radionavigation Plan, they say this will not be shut down until we have had the agreement of the other 8 countries. They just finished building the last transmitter 2 years ago in Australia. Now they are talking about shutting it down. All the countries that contributed transmitter sites and shared the costs of running the transmitters and so on are going to be very upset if they do it precipitously.

Richard Langley: You should also point out that although GPS is almost entirely funded by the U.S. government, there are agreements in place so that all NATO countries will be able to use GPS and be involved in future developments. Some tracking stations are on NATO soil. So it is not entirely U.S.

Dave Wells: In fact I think this is the first major U.S. development project where NATO was brought in at the beginning. As part of the headquarters of the GPS development team there is a NATO liason officer who keeps all of the NATO countries informed. In fact Canada has a representative down there.

Angus Hamilton: As far as shutting it off entirely, you have to consider that if they do that they ground everything that is moving in the U.S. DoD. They obviously are going to be using it not only for aircraft but for ships, tanks and all sorts of things. So the odds of it being shut off are just about nil.

Dave Wells: Unless somebody shoots down the satellites.

Angus Hamilton: Yes, that is obvious.

Dave Wells: We'll have more things to worry about then.

Richard Langley: Like finding the nearest hole.

John McLaughlin: There may be another technology coming down the road that will replace GPS.

Dave Wells: Sure. No system is for ever. The Transit system has had a lifetime of 25 years.

John McLaughlin: Those questions are not really even very interesting to us as long as you are talking about GPS as a tool to assist and maintain the full system we have today. It is only the next step when you talk about using the satellite network as your reference base.

Dave Wells: It is always a relative system though and any replacement would be used as a relative system.

John McLaughlin: But it does raise some more issues.

Richard Langley: Another thing that hasn't been raised is the depreciation of equipment. When you should get in; when you should decide to buy. You should probably keep in mind that it may be after 5 years you are going to want to replace that equipment anyway. It seems to be the way things are going with other types of equipment in the surveying industry. You have to be prepared to write off that investment or investment cost over say a 5 year period.

John McLaughlin: The trouble is if you are buying at the end of the cycle, your 5 year period may not look attractive against the guy buying at the front of the next cycle.

Murray Banks: We are going to have a real adjustment problem when we start tying in some of these ground posts that are about 20 miles into the woods.

Lewis Carr: We've talked a lot about government and LRIS, which we don't consider to be government, and the private surveyors. Has anyone considered if this is inevitable, and it appears as though it is, what scenario would be put in place whereby this arrives in some kind of systematic fashion? We don't want people dashing off with these little boxes generating values and not really knowing in what fashion we are going to do it. For example, with a first-order control, second-order control, etc., where does this fit in with the Maritime provinces? How does it filter down to the working surveyor or the working user or whoever it may be?

Dave Wells: Those are some big questions. I don't think anyone has any answers right now. There were some suggestions a few years ago that there be a central agency, like LRIS or the Geodetic Survey or the provincial survey organization or whatever, to maintain the coordinate system for their region, which would mean running some of the monitors. Users would then need only one receiver as a minimum. They would either get the correction data from the agency or would provide their data and have the differential position computed and supplied back to them as a service by the agency on some kind of cost recovery basis. That agency could be a government organization, or it could be some contractor to a government organization, or it could be private enterprise that went into business to provide this kind of service. It is unlikely that the private enterprise option would occur until there was an appreciable market.

John McLaughlin: Given the nature of the land survey business in the Maritimes, the chances are the private surveyors are going to learn about it by reading it in the newspapers. There will be companies coming in that have nothing to do with surveying, doing geophysical work or forest inventory work or something like that, and the surveyors will learn about this technology from an entirely different perspective. The problem then arises that you are going to have all this information being collected and there isn't any kind of a systematic framework for that exercise. If LRIS hasn't already developed a strategy of how they are going to coordinate these activities, then you may have everyone off doing his own thing. That is probably the way the land surveyors are first going to hear about this, that is, when a company shows up that has nothing to do with land surveying.

Mary Ogilvie: Dave, you mentioned that Alberta is using GPS at 250 points a year or so, and the Feds are into it and I know the Aussies are doing it. Are they doing it because it is cost effective?

Dave Wells: Well $3,000 per point—is that cost effective?

Mary Ogilvie: No, it wouldn't be here.

Murray Banks: That $3,000 was just because they couldn't find the darn things wasn't it?

Dave Wells: Well they had to find them and there was a lot of work involved.

Murray Banks: You get a 37 man crew and the cost soars.

Dave Wells: Yes, sure. The first government contract in Alberta was in the Crows Nest Pass where they were doing something to the road going through the Crows Nest Pass. They had very little control but they had good control points up on the mountain peaks around it which they wanted to bring down into the valley. They did that with GPS on a competitive basis. They looked at other alternatives which were going to be more costly any other way. So that was an example where it really did pay off. That was early in the game. That was the first actual use of the Macrometer in Canada.

Angus Hamilton: If you look at points on flat land, say a township corner every 6 miles, and start doing that by ground methods, you are either into towers or you have to cut lines and survey at $2,000 or more per mile. It is a matter of looking at the alternatives.

Dave Wells: If you have an intervisibility problem, GPS is going to be more cost effective than if you don't.

Angus Hamilton: For Murray's bush lines, they can go back 5 or 10 miles, select some good identification points, and put them in without a lot of clearing. Then they can use photogrammetry to interpolate and put whatever marks are needed.

John McLaughlin: If you have enough control to write off the cost, that is going to be another issue too in private companies here and in the west where putting in the control survey is a major task. You have to have enough work to write this off. This isn't the first new technology to come along that held out some major promises. In the 1960s a lot of work was done suggesting that we could do land surveying using photogrammetry. In fact for 2 or 3 years, if you look at *The Canadian Surveyor*, there was just as much hype about the photogrammetric possibilities in cadastral surveying as there is for GPS today. In the end it never really developed. It had nothing to do with the technology, which was of good quality, and it really didn't have anything to do with the costs. It turned out the problems were more non-technical and more institutional. It was because the land surveyor does the survey on a project basis and you don't get any systematic flow through process that would justify bringing in the photogrammetry. In other words you get a lot of overhead costs but you can't charge that off against one parcel or a couple of parcels. The thing broke down for non-technical and non-economic reasons. I suspect we have a problem with GPS right now, though I haven't got a clue what it is, that is going to be something like that. It is not that it isn't technically feasible, or even that some of our economics don't look attractive, there are some other issues that may emerge that limits its use.

Murray Banks: Of course in our English common law system, which we have in N.S. and the same here in N.B., on your old compass lines that run through the woods, every one of the blazes through that line, if we can find them, is a monument. We can't just simply take and cut in a straight line between those crown posts and say ok there is the line, because the courts have already established that the boundary follows that blazed line through the woods. It may have been set there 150 years ago.

John McLaughlin: I was thinking of that earlier when somebody said that strictly speaking in land surveying you not always in the point positioning game; there are curvilinear lines that have a life of their own. You can try to define it, delimit it in terms of finite number of points, but in fact that line itself has certain significance and you are giving an example now. Those are the non-immediately perceivable problems that we may get bogged down with.

Murray Banks: I think Lew raised a very interesting question here. I think traditionally, down through the years, government, like Geodetic Survey of Canada, set the primary control and either provincial governments, for example, LRIS here in the Maritimes, have set the secondary control. I think the private sector looks to government for the control. In N.S. we have passed an act through the legislature, when the control system was coming in, called An Act for the Establishment of a Control System. It never was proclaimed but it was actually to make the control system legal so that surveyors could tie into it without legal surveys. I can see where there may be a need for some legislation somewhere down the road to have one agency responsible for setting the primary control to tie legal survey into.

John McLaughlin: We have that in N.B. We have the Surveys Act, we have the coordinate system defined in the act, and we have the Director of Surveys spelled out as the officer responsible for it.

Murray Banks: As I was telling somebody this morning, in N.S. we are always behind N.B. We haven't done that. There is nothing in N.S. yet except the Land Surveyors Act which doesn't even specify that you have to tie into a system. So instead of having everybody running off in all directions setting their own control and so on I think there is going to have to be some legislation in N.S. at least to say just who is responsible for the control. When you are talking about legal surveys, you are into a whole new ball game. If we were just talking about finding a position at a given point on the surface of the earth, to the user who has to use that in the legal sense it is another ball game.

John McLaughlin: Just a smaller point. Land surveying obviously is the sphere I am interested in and for the plane coordinate system developed in the Maritimes that is probably one of the two primary uses. One of the things we do have to think about with GPS is the cost of positioning coming down so far that it opens up this game to a lot of other uses, some of which may be far more important than property surveying in terms of the amount of work that's done. So we may have some big communities that blow away this focus we have had on the land surveyor.

Dave Wells: Any ideas?

John McLaughlin: Yes, but they are pretty speculative. I think the forest community could be collecting a lot more information than they have in the past. I can see water quality information being a big application. Information is being collected right now that isn't positioned to put on a map or whatever because of the cost associated with going that extra step.

Adam Chrzanowski: Similarly, the geological information would be positioned by coordinates.

John McLaughlin: Logging information, all kinds of drilling information.

Richard Langley: Keeping track of vehicles. Both the mining and forest industries are seeking ways to keep track of their vehicles. A mining company out west is looking at ways to keep tabs on their trucks.

Murray Banks: In the wildlife division under lands and forests, the way they count moose and deer now is from an old Beaver aircraft stationed at Waverley. Once we get down to the $10 instrument, as mentioned this morning, it could probably be used in wildlife studies by injecting a receiver into a moose and tracking their movements.

Lewis Carr: It would probably end up in someone's freezer.

Murray Banks: A great way for the Rangers to find out where the poachers are.

John McLaughlin: It does mean a shift in thinking for the control survey division. The control survey people had to be surveyors and they had to relate to surveyors. They talk to land surveyors about their problems and they will have to begin to think about this broader community of potential users. I think one of the potential impacts of this new technology is that it is going to change the mix of users that you get.

Wolfgang Faig: Also there would be three-dimensional positioning. I think so far control surveys have been basically two dimensional but the vertical information was just tacked on with very little importance to it. If you have that with it, consistently and at all times, that opens up a whole new possibility.

Lewis Carr: Just as an aside to what you mentioned as other uses, there is one I'm trying to implement now for our highway systems. There are numerous logging areas, mining areas, and highways in our province and I assume it is the same in yours. Historically, these have not been mathematically defined at least not by a coordinate system. When this comes on line, especially when you get down to the cheaper receivers, where you can generate mathematical values practically as fast as you could drive or walk, it definitely would have an application there in forestry.

Mary Ogilvie: Those gadgets that are going in the cars now, are they useful here at all, or are they included here in the Maritimes or anyplace?

Dave Wells: Which particular gadgets?

Mary Ogilvie: Well, you talked about these little mini-receivers; a $500 option that you put in your car that tells you where you are. How can they tell you where you are if you are not a surveyor?

Dave Wells: I think you are talking about GPS.

John McLaughlin: If you're talking about an electronic chart, who is going to build them for the Maritimes.

Dave Wells: Well, yes, someone has to digitize the road maps and put them on a compact disk.

John McLaughlin: That's right.

Dave Wells: Again, I have a couple of papers that I can pass along. This is one from Phillips Electronics in the Netherlands "Application of the Compact Disk in Car Information and Navigation Systems." There is one page describing how GPS is going to be tied to a compact disk by Phillips. Note that Magnavox is a subsidiary of Phillips. This other article happens to be in Dutch. It shows a prototype and a little picture of some of the GPS satellites and how that would fit into a car information system. But Chrysler probably had an empty box. They demonstrated one thing labelled GPS Receiver and another labelled Compact Disk. Then a little display that was supposed to show a map. I think this is what we are talking about. It is useless to have the GPS option built into cars until after 1989 when you will get continuous coverage. But along these lines, Tara Surveys in Toronto have a contract with the Ontario government to provide an electronic chart in ambulances. The idea is that the dispatcher and driver will each have displays and they will be starting off using Loran-C because that is available now. They will switch over to GPS in 1990. The way it works is that it has all kinds of little sensors, not just a navigation system. Something is tied to the odometer, the steering, and so on, so it does some dead reckoning as well. The idea is that the dispatcher can say: "You want to go three more telephone poles past that intersection." He will know where the ambulance is because it will be able to radio its position back from what it measures. They can calibrate the positioning system, GPS or Loran-C, because as they go past an intersection, they set the cursor on the display at the intersection, and press a button which registers the navigation positions to the map positions. They were talking about this a year ago when I was at a meeting at Ottawa. The system was delivered to Orangeville in 1985 as a pilot project. If it was successful, they would get a contract to supply these for every ambulance in Ontario in the next 2 or 3 years, and if that was successful, they would be ready to take on the world. So it looks as though there is at least one Canadian company tied to the surveying industry, at least peripherally, who is moving into this car information system technology already.

Angus Hamilton: It is a natural extension from the marine one. In Washington, Mort Rogoff is using differential Loran. Dave and I have been on his boat in Baltimore harbour where they could come very close to a buoy and show on the screen which side they were on. The technology is there and working. The Japanese are selling thousands of these receivers for fishing boats and they keep track of where they are, and where they got a good catch of fish, so instead of putting a chalk mark on the side of the boat, like the Newfie joke, they can put an alphanumeric notation in their data base: its closer than we think.

We scheduled this for general discussion and we've certainly had a general discussion. We wanted to raise questions, which we have done. Are there any other technologies that should be considered as alternatives or as complements to GPS, and if so, which and how used. I think that is where Adam suggested inertial.

Adam Chrzanowski: Inertial would be only for very special uses, like highway surveys, but not really for legal surveys, unless the price goes down. I think we should still keep our theodolites ready to work.

John McLaughlin: Once you have this you still have the setting out problem in which the total station is going to have a big role to play.

Adam Chrzanowski: But with this latest application in the continuous signal locking mode it looks like in seconds we can also get the positions of other points, if they are near the master station. This could replace many of the conventional setting out surveys.

John McLaughlin: It will be later in the process.

Adam Chrzanowski: Yes, later in the process.

Angus Hamilton: The question George Schurman and I addressed last week was procedural rather than technological. Is there a benefit to using dual purpose monuments? In other words, when you get away from the intervisibility requirement a lot of things open up that may reduce the need to put a special marker in the ground which serves no purpose except being permanent. Something permanent on a lot corner is useful as it has a legal standing in its own right; if it also serves as a control there should be immediate cost saving. There are a lot of scenarios on how we can change our way of thinking and doing things.

Dave Wells: May I just raise a question? When you go out and do a maintenance or densification survey, on the occasions when I have used LRIS control, and I actually have, I found that every point unless it is destroyed is visible to the one before and the one after.

Bill Robertson: You were fortunate.

Dave Wells: Is that still the policy when putting in new control, that you have a string of points that are intervisible?

Adam Chrzanowski: We need orientation.

Dave Wells: But do you have to have intervisibility between every pair? Can you have 2 points here and then 2 points 2 km away and not put any monuments between?

Bill Robertson: Yes, of some sort. There are different types of monuments. In some areas, where we can't get the spacing, it is desired to put an iron bar in which is recognized as a lesser quality monument. So, if you have a choice of using as a reference an iron bar or a monument, you would choose a pair of monuments. But we don't go around clearing lines.

Dave Wells: No, you usually follow roads.

Bill Robertson: One question we get asked by a lot of the survey firms is why don't we clear the lines between monuments when we go back and find them blocked. Why are we not spending a lot of money and a lot of time to clear the lines?

Murray Banks: As a user, there are other ways of getting around blocked sight lines. When power corporations come in and put a pole right bang on line, there are other techniques you can use to solve that problem. I have even had occasion where we had only one monument left on an end of a survey I wanted to tie to. Then you do either a star program, or solar observations with Roeloff prisms, or whatever, to get your closing azimuth and you can come up with some darn good closures. So it is not absolutely necessary that the user have intervisibility, but I think when setting them you pretty well have to.

Wolfgang Faig: What kind of legislation do you have to protect your monuments or do you have any?

Lewis Carr: Transportation overrules!

Wolfgang Faig: I find it surprising. The City of Fredericton has no hesitation in pouring a new sidewalk right over a monument so that it disappears from one day to the next. They don't even put a little iron cup over it or anything.

Bill Robertson: It depends on how good our communication is with the local people. This is where regional offices can really play a part. In a lot of the areas where we have regional offices, we have good communications established with the local officials and when they are going to put in a sidewalk they will come to us and we give them a cover and they'll put that over the monument.

Wolfgang Faig. It would be nice to have some legislation with penalties if they destroy a monument.

Murray Banks: In the Criminal Code of Canada, section 391, you can get 5 years in prison for destroying a survey monument as long as it has been set by a licensed land surveyor.

Wolfgang Faig: I have an example. I was away for a year, came back and sent my students off on a lab to find a monument on the corner of Albert and Regent Streets. A new sidewalk had been put in while I was away and the monument had just disappeared.

Bill Robertson: There should be a cover now as we just did an inspection in Fredericton this year.

Wolfgang Faig: It is just paved over. There is nothing there.

Murray Banks: The first court case in Canada under that section of the Criminal Code was held just a few months ago in Bridgewater, N.S. The party was found guilty of destroying the monument and there were even dollars assessed in the amount of damage but because the judge couldn't find any precedent in Canada, he gave a total discharge and the defendant walked out of the court room without paying a fine or anything. The Crown decided for some reason or other not to appeal. So we still don't have a precedent.

Wolfgang Faig: Now you have the precedent set the other way.

Murray Banks: Right, that is why I don't know why they didn't appeal it. Our association of land surveyors in N.S. has sent a strong letter of protest to the attorney general but that won't mean much.

Wolfgang Faig: If you spent $500 to recover or rebuild a monument that is just destroyed somebody should be liable.

Earl Robinson: Some people are more considerate. N.B. Tel and the highways department pay for monuments they destroy.

Angus Hamilton: That is really getting into part two of the study. Can we focus on the upcoming technology. The second item was equipment cost. Dave I think has given us everything that he has to date. We will recap those and send them out. They will be in the report when we put it together.

The next question on our list hasn't been discussed and I think that it is relevant. The data processing and the expertise that is required now and the expertise that will be required for the first operational stage or the first generation of operations. I think we have been very glibly talking about how many minutes it takes on the station to get the results, but Dave mentioned earlier when going over the fundamentals that this target record has to be taken back and data from two stations has to be brought together and processed before you have a result. I think we should have a discussion on that. Dave, could you elaborate a little bit on the level of expertise required.

Dave Wells: I guess we have had an example with the Usher and Associates contract in Alberta. Last year they leased the equipment from Geo/Hydro in the U.S. and they also rented the services of an experienced operator to teach their operators how to operate the Macrometer. But they did everything else themselves including the processing of the data, and they used the Geo/Hydro software or the Macrometrics software using that little processing unit that I showed sitting on the table in the slide.

This year they decided they would process the data using their own software or software they didn't rent from Geo/Hydro and they opted to get a free copy of the software that we developed in our department under contract from the Geodetic Survey of Canada. They have a computer that is almost exactly the same as the HP minicomputer that we used to develop the software, but there were some problems getting it to work on their computer. It turned out that they were not enforcing the right options and this kind of thing. So it ended up that one of their programmers or computer operators or surveyors flew down and spent a week with the people who had actually written the software to find out just how to operate it. We thought we had produced a reasonably foolproof operator's guide as part of our contract. My understanding is that experience was successful and they will be using our software in the processing of the data on a day-to-day basis. They will be using 4 or 5 receivers, processing each day's data as a subnetwork to clean it, and then at the end do a larger network adjustment using other software. Our software massages the GPS observations down to baseline solutions and then they'll put the baseline solutions into a network solution of their own design. The 200 station networks they are putting in are, I believe, the most ambitious networks that has been put in anywhere in the world so far. They seem to be able to handle it, although last year with the software they were using they ended up making runs that lasted 67 hours on the minicomputer and then finding they had put the weighting in wrong and having to rerun it all. They did that 2 or 3 times.

Richard Langley: It turns out that their major problem was not with our software but with the test data that the Geodetic Survey of Canada sent them. The test data was supposed to have a format length of 130 characters, or something like that, and Geodetic Survey cut it off at 80 so, of course, they were trying to process faulty data. That is one of the things that came out of the test.

Dave Wells: I think that there is a short term answer and a long term answer. The short term answer is that there are a few packages floating around. There is our package, there is a package that has been developed at MIT, there is a package that has been developed at the U.S. National Geodetic Survey. At least the NGS one and our packages are freely available so that there are several firms that have got copies of either or both of them and are testing them and using them. The longer term solution is that when receivers, like the Wild-Magnavox 101, are available, it will come complete with self-contained processing software; maybe not the first couple of deliveries, but as a retrofit. It will be a black box and Magnavox will probably not give out a lot of information on what the software does or how it is designed so one has to evaluate it and calibrate it and trust it and this kind of thing. On the other hand, I suppose the same thing goes with our software. Although you may be able to read it, it may be just as much of a black box. There is no reason why the software can't be installed on a fairly powerful personal computer. It would take longer to run, but I think depending on what you are doing, if you are doing single baseline solutions, it should run on one of the higher-powered IBM PCs. What we hope to do is put it on a Macintosh. If you are doing a lot of stations, you probably need a little bit more memory and it would take a little longer to process. It could be done on a mainframe like the IBM 3081 at UNB.

Bill Robertson: Is it operating on your mainframe at UNB yet?

Dave Wells: The latest version is on the Hewlett Packard 1000 mainly because we can get easier operator interaction, and this kind of thing, on that computer than we can on the IBM. It doesn't really need the power of the IBM. Our first package took 20 hours to run on the HP and this one takes 20 minutes. So we have made some improvements.

Murray Banks: I probably missed something, but where are you getting your data to run through the program.

Dave Wells: We are in the fortunate position of being asked to participate in various campaigns and get data in return. Some of the data that I showed you was from a Macrometer test of a network done in Ottawa in 1983. That was re-observed with the Nortech TI receivers under contract to the Geodetic Survey and that was given to us to process. We have done a comparison between the TI results and the Macrometer results on the same network a year apart. There was a network of small extent, like a couple of kilometres across, that was done by Richard Moreau in Quebec City for the Quebec government, and we participated in the processing of that data and have used it to test our software and evaluate GPS. We have a long list of the data sets we have, but we haven't been able to process them all because we have run out of students to assign them to as projects. But we have the data that you mentioned from the Alaska network and then there is this bake-off data which you have heard of.

Richard Langley: GPS test, 10 stations, 3 different receiver types, some operating on the same baselines.

Dave Wells: The thing is we have the reputation for having some good software so everyone wants to see if we can get more out of their data than they can with their software so we have no problem getting data. We have more data than we can handle.

Angus Hamilton: One of the things that occurs to me is there is an analogy here between the experience with digital mapping whereby LRIS seconded somebody to work with the group in our department well in advance of the time they got the equipment. That was a new technology and there was no other way to go. I'm just probling to see whether this is new enough and different enough, whether something like this should be entertained as well.

Dave Wells: I'm sure we have lots of projects we can use to acquaint someone with the technology. One thing that comes to mind would be to transfer our software to a VAX computer so that it would be more compatible with the kinds of things already done.

Mary Ogilvie: Does anyone have enough of a feel for the level of knowledge needed by the private surveyor? Would it take a day lecture, or a week or what?

Dave Wells: The CIS sent out a questionnaire over the summer to the membership asking what the interests were in about 16 topics for continuing education for surveyors. The top two topics in demand were, "Concepts of GPS", and "Applications of GPS". Then land information systems were the next two topics in demand, and so on down the line. It seems that there is a demand out there now. There has been enough noise about GPS that there are quite a few surveyors that would like to hear more about it in an introductory way.

John McLaughlin: What did Usher and Associates have to do to get into the business in terms of personnel.

Dave Wells: They just jumped in. They had 3 or 4 surveying engineers and I guess they read up on it, but we didn't hear a word from them. They sent us a letter about the time that they got the first contract saying here is what we are doing, we want you to be informed, and we may be asking you some questions. They were essentially renting the expertise last year from Geo/Hydro. What we have been discussing with them is the scenario that Angus has suggested that they identify an employee that they would send either for a Masters or for a period of time to work with us on some special project of some mutual value. Or else we could identify a promising student that would be interested in graduate work with their financial help. They are looking at these options right now.

Wolfgang Faig: How much time does it take, a week workshop?

Dave Wells: One of the questions in the CIS questionnaire was: Would you like to see a one-day course, a five-day workshop, a one day a week for a term or whatever? The two day format seemed to be the one that people were most interested in. I think in two days all we can do is acquaint people with the system and the issues; we are not going to make anyone into an expert GPS surveyor in two days, but we can raise the questions they are going to have to deal with. We can give them some of the answers.

Mary Ogilvie: Would they end up feeling comfortable with data processing?

Dave Wells: No, because that is tied very closely to a particular package. The data processing that you might do using the built-in software on the Wild-Magnavox 101 would be very different from the data processing using Klein Goad's software from the U.S. National Geodetic Survey or our software.

Richard Langley: But what you can do in basic terms is know what is going on inside the software, what the observables are, etc.

Dave Wells: There are two aspects there. We can acquaint probably any surveyor in the country with the concepts and the potential impact and the applications, but to get into the details of the software you would have to have a surveyor that had some experience programming or some mathematical background. I don't think we could take just any surveyor. They have to be comfortable with matrix algebra and that kind of subject matter. That would be quite detailed of course. It would have to be a third course I think. A pair of two-days courses, one on concepts and one on applications, would go as far as saying here is how the software runs, here is how you find the design matrix under these circumstances, and that sort of thing.

Murray Banks: Is it really necessary for a surveyor to understand how everything is working inside a computer? It doesn't take long to show someone what they have to put in as long as he doesn't have to know what is happening inside.

Dave Wells: I think that is a question that each surveyor is going to have to answer for himself. Just how much is he willing or wants to invest in the technology. Does he want to be purely a consumer of the technology and trust it and then get disappointed when somehow it doesn't work out?

Murray Banks: When the geodimeters and telurometers first came out we were scared to death of them, so we had short courses around the province trying to learn how to use these things. Then we went out on the tundra in Labrador trying to use them, and we would taking out something because it got a little moist to try and dry it out over the fire and all kinds of things. Now you can set one of these things and push a button and show a 10 year old kid how to do it in less than 5 minutes.

Adam Chrzanowski: It would be the same because with the first geodimeters and telurometers, you had many aspects of the measurements which could be influenced by the operator. Now with the fully automatic system you don't even have to know what is inside. It would be the same with GPS.

Angus Hamilton: I would like to excuse myself. I'll ask Adam to monitor the discussion.

Adam Chrzanowski: Are we supposed to conclude anything today, or is it just to prepare for the second session; what we would like to say in the second session?

Angus Hamilton: Just conclude what the state of the art is; how we apply it is the topic of our next meeting.

Adam Chrzanowski: The remaining questions on this list are not really relevant right now, like data processing cost; what is the approximate cost now for computer time for personnel. We have some insight from the earlier presentations on the cost and maintenance of the network, and establishment of the points. I think the purpose of our study is to get at least an outline of the future activity of LRIS concerning the new technologies coming. I think that this should really come from LRIS. After listening to our short presentations, which way should we proceed in the near future. We cannot wait. I think we have to make some decisions pretty soon, otherwise the surveyors, as John mentioned, will learn about these new technologies from the newspapers. It would be better if they learned from the proper sources.

Murray Banks: As a member of the Association of N.S. Land Surveyors, I can foresee one or two seminars just next year. Invite all the surveyors in, bring in some people like Dave and yourself to give them an overview. I think they will start to get excited about it once they know what is happening around them, but so many of them are so busy in the woods right now that if you mentioned GPS to them they wouldn't know what you were talking about—whether it was a new disease or something to eat. They are just too busy working and a lot of them are just not keen enough on reading up on the subject. That has been my experience in attending just some of the zone meetings.

Dave Wells: What is the best way to organize this sort of thing—as part of the annual meeting or something?

Murray Banks: No. There is a continuing education committee in each association and that committee is supposed to be organizing seminars during the course of the year in continuing education to keep surveyors abreast of new developments. In N.S. they attend in droves if you talk about something from the legal point of view, for example, if you bring in someone like Dr. McEwen to talk on the legal aspects of surveying. For GPS we would have to do some selling to get them in or make it pretty attractive to bring them. I think that can be done. But I am concerned already that a lot of our members just don't know what progress is taking place around them. I think what we are talking about today is pretty exciting stuff and it is an evolution that is happening now. I think it is something bigger than when EDM came on stream. We thought that was really something. When we were talking about accuracies this morning, someone was concerned about being out by 5 cm. It was only a few years ago that we were chaining with tension handles and making correction for slope and sag and if we got a closure of 1 part in 5000 we were just excited as anything. Now it seems to me we have gone the opposite way. A surveyor was complaining because he was off 5 cm. That is just unreal. They are like kids with new toys when they have EDMs. We have to do something to try to get our surveyors on track.

John McLaughlin: EDM was revolutionary. It wasn't revolutionary just because of the new accuracies. After all, it was EDM that really brought the idea of using coordinate systems and to begin to think of surveying from that perspective. That is probably what is going to happen here again. It is not just that you are going to improve doing what you have done, but it gives you a new way of rethinking the whole process. EDM did that. There were a lot of technologies that appeared over the years, but EDM itself was a revolutionary technology in the sense that it made the whole idea of using plane coordinate feasible in Canada. Without it, there would have been no LRIS, for example. EDM was one of the basic technologies in the idea of building plane coordinate systems. GPS could have the same kind of impact. Ten years from now we could be sitting in an entirely different environment as a result of this thing.

Murray Banks: Like everybody else, I was pretty excited about inertial survey systems at the time, and there were conferences in Edmonton and Quebec City and so on. But that never seemed to really get off the ground for private users. I think this GPS will from what I see. I think it is going to be accessible to the little guy and not just to the government or corporations with the money.

Lewis Carr: It really is an extension of the existing monumentation system rather than the concept of it. When we brought in the original monuments in N.B. I remember there was a horrendous problem, a PR problem, much the same as we are talking about with GPS. Courses were given to the surveyors, who were basically chain and compass surveyors, and they were learning about a new system that involved no physical measurement at all with tape or anything to tie into the permanent monuments and carry the coordinates. It was too much to swallow and, as a result, some of our surveyors are still in a bit of a fog, 10 or 15 years after the fact. I am of the same opinion that this GPS has to be sold starting now and for a long time before the technology even arrives. It has got to be sold in introductory courses and slowly move people along so that when the technology arrives they will at least have some background knowledge. This course is preferable to waiting until it is here and then saying all right, we are going to give you a course this afternoon on how to do this and you'll be able to operate it. That is what happened in the monumentation system in N.B. It was an unfortunate circumstance. There was a group of people who knew the business and EMR was the unit that knew what was going on, but the surveyors for some reason or for various reasons were not really involved in it. They seemed to say I don't want anything to do with it until it is absolutely essential. So, it is a PR problem.

John McLaughlin: In the first paper we did on GPS a number of years ago we traced out how long it took for EDM to be introduced and it took from the time you were at the stage you are now with GPS until you virtually saturated the market with EDM equipment. EDM began in the 1950s. The early 1950s for EDM is comparable to the 1980s for GPS. Around 1965, about half the land survey firms had EDM equipment. We were projecting in that paper that this cycle for a number of reasons would shrink to about half that so rather than taking 30 years, it would take say 15 years. That meant it would take 7 to 8 years to get to that half-way point, whatever that half-way point is.

Adam Chrzanowski: No, it can happen much faster because the general education of surveyors is better than it was 20 years ago. It was only through the lack of education 20 years ago that it took such a long time to accept a new technology. Somebody who doesn't know how to cope with the new technology will not use it. He is afraid of it. I think that right now the standard is higher so the acceptance would be higher.

John McLaughlin: That is why we are predicting it would take half the time.

Earl Robinson: I think technology is changing faster now. GPS would improve faster than EDMs did.

Murray Banks: There is some thrust to do away with the compass completely.

Dave Wells: I don't think you want to destroy those things you can actually see.

Murray Banks: Being a hunter, I want to mention a few things. I can just visualize one of those little wrist watches that Wolfgang was talking about that would give me my position instantaneously for about $10. With my map and the wrist gadget I'll know exactly where I am at any time. Whereas now when you haul out a pocket compass, all you know is that magnetic north is off there somewhere, but it doesn't really tell you where you are.

John McLaughlin: Some would like some kind of little cruise missile to take care of the moose too!

Adam Chrzanowski: So now who from LRIS would give some concluding remarks then we could quietly go home and be satisfied that we have accomplished something here today.

Bill Robertson: I think certainly from my point of view I have enjoyed the day and I've learned a lot. I am not just exactly sure where we go from here. I was wondering if you are saying that we should develop our own futures. I think maybe we are looking to you to suggest what that future might be. I think we are in a quandry about what we should do about the maintenance of a network. I'd like to see UNB suggest that the system should go on, or that it should taper off, or something like that. I'd also look forward to a suggestion from you people whether we should be starting with GPS. I'm not sure that that is a good concluding remark.

Adam Chrzanowski: I think that Angus has suggested that we should meet again early in the winter. I don't know when early winter is in N.B. I don't know what the schedule is.

Mary Ogilvie: I think there is supposed to be a draft report written early in December and a final in March.

Adam Chrzanowski: Before the final report, we should have a meeting, so perhaps the end of January or February. In the second session, we could come with some more concrete proposals to discuss together and draw some conclusions for the future. Then maybe it would be time to discuss how to handle the general surveying population as far as the new technology is concerned.

Mary Ogilvie: I can see why that bubble chart gets so much mileage. I found it to be very meaningful.

Adam Chrzanowski: We will have to start changing colours on it now from time to time.

Murray Banks: I certainly would like to thank Earl for inviting me. I think I'm the only person here from N.S. and I certainly have found the day very informative. I can assure you that I'll be going back to spread the message the best I can. I have let my name stand for nomination to council again and if I am elected, as I said in my platform, I am going to make sure that there is some continuing education seminars next year, and this would be one of the topics that I certainly would be putting forward.

George Schurman: I would like to take this opportunity to thank Earl again. I think I can say with some certainty that the general surveying population is certainly going to be relying on what we can get from LRIS and from UNB because we are going to be looking to you fellows for guidance. Professionally, I will be asking the general surveying population what they want. They don't know, so we will be looking forward to you fellows to tell us and I think we want some information so we can make our minds up. I don't think you are going to educate 90% of the surveying population to understand what is going on. We are going to have to take it and accept it the same as we did with EDM or a computer or the coordinate values that you give us.

Adam Chrzanowski: Any other remarks?

Lewis Carr: I would like to say that I enjoyed the day. I know a lot more about global positioning than I did when I came in. From the discussions, it appears it is one of those technologies that is imminent and I just hope that we can keep pace with the advances in the technology.

Murray Banks: I don't know what's wrong with replacing EDM.

Earl Robinson: Thank you very much gentlemen.

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