

22 July 1971

1. Historical Data

(a) Title: TIMATION Navigation Satellite Technique

(b) Brief Description of Objective: The primary objective of this project, initiated in FY 1965, is to determine the feasibility and develop experimental proof for an advanced navigation satellite system using the TIMATION technique. This goal is to be reached through the fulfillment of subordinate objectives, such as the launch of experimental satellites for real time tests using experimental receiving equipment. The Exploratory Development program was successful in demonstrating the objective of proving the feasibility, and in FY 1970 the project was advanced to the Advanced Development category. Commensurate with entry into Advanced Development, Advanced Development Objective (ADO) 34-11X, "Defense Navigation Satellite Techniques", was issued, which set the objective of demonstrating the utility of the technique. To that end the development is now directed.

(c) Time Period Conducted: The project was initiated in FY 1965 and is continuing.

(d) Major Milestones:

System Concept	April 1964
Project Initiated by BuWeps	September 1964
Ranging Experiment with Transmitter in Moving Vehicle	March 1965
Satellite System Design Started	October 1965
Ranging Experiment with Transmitter in Airplane	November 1965
Concept of using Celestial Navigation Techniques with Satellite Ranging	December 1965
First Space Flight Qualified Highly Stable Oscillator Delivered	May 1966

Satellite and two Ground Stations completed (NRL and Raymondville, Texas)	November 1966
TIMATION I Satellite Launched	May 1967
Initial Satellite Clock Synchronization	June 1967
First Fixed Point Navigation	June 1967
TRANET Tracking Data used for Tri-Service Navigation Demonstration	October 1967
Time Transfer Demonstration for the NOTS (Naval Observatory Time Service)	February 1968
Time Transfer Cooperative Program with NOTS started	March 1968
Time Transfer Cooperative Program with the Bureau of Standards, Colorado started	March 1968
Moving Navigator Demonstration with TIMATION I	Jan-May 1968
The HYBRID (Ranging combined with Doppler) Navigation concept confirmed with TIMATION I	August 1968
RCA Study on Combining Ranging to Navy Navigation Satellite System Issued	June 1969
TIMATION II Satellite Completed	August 1969
TIMATION II Satellite Launched	September 1969
First RCA Study on TIMATION System as the Defense Navigation Satellite System Issued	November 1969
Eleven TRANET stations worldwide tracking TIMATION II	April 1970
ADO 34-11X Issued	April 1970
TIMATION II Tracking Data used for Geodesy	May 1970
NAVAIR Assigned as Principal Development Activity for ADO 34-11X	August 1970
Research and Development Project Summary Form DD1634 Issued in lieu of a Technical Development Plan	March 1971
TIMATION III Satellite Design Started	April 1971

Signal Modulation Study Initiated

May 1971

(e) Dollars and Manpower Expended each Fiscal Year for Direct Laboratory Support:

	FY65	FY66	FY67	FY68	FY69	FY70	FY71
Category II Funds(\$K)	75.0	847.5	522.0	1813.4	1820.0	377.0	784.0
Category III Funds(\$K)	--	--	--	--	--	1348.5	1195.0
Man Years	1	8	14	38	44	30	30

(f) Resulting Products: The results of this project have been primarily experimental satellites (TIMATION's I and II), receiving hardware, and corresponding experimental results. The majority of results have been contained in letter and progress reports.

(1) Formal Reports: Formal NRL reports resulting from this project are as follows:

NRL Report Number	Title
6389	Transistorized Digital Clock with Serial Binary-Coded Readout
6633	Ranging and Velocity Experimental Equipment
6781	The TIMATION I Satellite
6928	Inclination Perturbations of Polar-Orbit Satellites
6824	Method for Calculating a Two Point Single-Pass Orbit
6896	Continuously Visible Satellite Constellations
6876	TIMATION I Ground Station
6861	Ionospheric Propagation Delay Measurement Techniques Using Dual Phase Coherent Doppler Frequencies and a Thin Shell Model
6850	Upper Atmosphere Density Determination using NRL Artificial Satellites

- 6782 The Thermal Design of the TIMATION I Satellite
- 7227 TIMATION Development Plan
- 7252 (In Press) Principles and Techniques of Satellite
Navigation Using the TIMATION II Satellite

(2) Formal Study Reports:

Grumman Technical Report MSSR-423-68-9, 'Satellite Stationkeeping to a Predicted Ephemeris', Grumman Aircraft Engineering Corporation, Bethpage, New York dated

RCA Report AED-M-3433-1, 'Range and Range-Rate Navigation Study Final Summary Report', RCA Astro Electronics Division, Princeton, New Jersey dated 5 June 1969

RCA Report AED R-3487-1, 'Defense Navigation Satellite System Study, Final Summary Report', RCA Astro Electronics Division, Princeton, New Jersey dated 19 November 1969

RCA Report AED R-3632F, 'Navigation Satellite Constellation Study, Final Report', RCA Astro Electronics Division, Princeton, New Jersey dated 29 Jan 1971

RCA Report AEDr-3665-F, 'Medium-Altitude Navigation Satellite System Definition Study', RCA Astro Electronics Division, Princeton, New Jersey dated 30 April 1971

(3) Statement of Results:

The TIMATION I satellite demonstrated the principle of navigation by passive ranging, the utility of the technique for time transfer, and the limitations of a single carrier frequency for ionospheric correction. This first satellite demonstrated the following findings:

- a. The Principle of Navigation by Passive Ranging
- b. The Utility of Passive Ranging for Time Transfer
- c. Instantaneous Fix by combining Passive Ranging with Doppler measurements
- d. The limitation of a single carrier frequency (no ionospheric correction)
- e. The limitation of a two oven crystal oscillator for maintaining accurate satellite time
- f. The shift in oscillator frequency with radiation.

Laboratory-type experimental equipment gathered data from this satellite while riding in aircraft, small boats, and trucks, thus demonstrating its feasibility and practicality in users. These tests showed that ranging is relatively insensitive to user motion whereas doppler measurements are highly sensitive to motion. However, it was suggested by RCA/AED, who were under a study contract to NRL, that the two techniques, i.e. range and doppler (range rate), be combined so that a two dimensional position fix could be obtained nearly instantaneously by simultaneous measurements. This method was studied, and experimental fixes taken to confirm this technique.

Experimental work performed with the first satellite led the way to dealing with problem areas, among these were ionospheric refraction, clock synchronization, satellite stability, and others. As a result a second satellite known as TIMATION II was designed and constructed incorporating lessons learned from TIMATION I.

The second satellite was improved over the first in the following ways:

- a. An improved gravity gradient stabilization boom
- b. Two carrier frequencies to permit ionospheric correction
- c. A quadruple oven crystal oscillator for stable satellite time
- d. A better crystal in the crystal oscillator
- e. A larger power supply for continuous operation

Most of the satellite functions have operated perfectly, however there has been some problems with the power supplies. Navigation and time transfer data is being taken and is now under analysis.

2. Summary of RDT&E Activities for the TIMATION Project

(a) Name and Branch of Laboratory: Naval Research Laboratory, Space Metrology Branch (previously known as Space Applications Branch).

(b) Brief Description: This project was initiated to demonstrate and develop an advanced navigation satellite system that could provide accurate position fixing to inexpensive receiving equipment and aircraft. The first demonstration of the TIMATION technique was achieved with the TIMATION I satellite, by which the proof of position fixing by ranging signals from satellites was confirmed. Tests were run with experimental receiving equipment in fixed stations, small boats, light aircraft, and trucks. As error sources and refined techniques were defined by the experiments and studies, the improvements were incorporated in the TIMATION II satellite. The TIMATION II satellite was used to first demonstrate improved capability, and second, the experimental results were used to project, combined with detailed studies, an optimum navigation satellite system that meets or exceeds all the requirements of the JCS Navigation Requirements published in 1968.

(c) Time and Period Conducted: The project was initiated in FY 1965 and is continuing.

(d) Funding Breakdown in \$K:

	FY65	FY66	FY67	FY68	FY69	FY70	FY71	FY72
Category II	75.0	847.5	522.0	1813.4	1820.0	377	784.0	831.0
Category III	--	--	--	--	--	1348.5	1195.0	4178.0

(e) Manpower Required:

	FY65	FY66	FY67	FY68	FY69	FY70	FY71	FY72
Man Years	1	8	14	38	44	30	30	32

- (f) Special Equipment Required: Various forms of special equipment have been, and continue to be, required for this project. The most significant of which has been the experimental satellites, TIMATION I and II. These satellites transmit ranging signals at 400 MHz (TIMATION I), and at 150 and 400 MHz (TIMATION II). The transmissions are controlled by highly stable quartz crystal oscillators developed especially for this application. Special receiving equipment was required to receive and evaluate the satellite signals. A brassboard 400 MHz user receiver was built and is currently undergoing evaluation with TIMATION II.
- (g) Relationships with Other Organizations: The system that could result from this project is a candidate for becoming the Defense Navigation Satellite System, which is under consideration by the NAVSEG (Navigation Satellite Executive Steering Group). The NAVSEG is examining and coordinating navigation satellite projects throughout the Department of Defense, and maintaining liaison with other departments and NASA. This project is coordinated through the NAVSEG, and is coordinated within the Department of the Navy by Navy Space Projects Office, PM-16.
- (h) Completion Date: The completion date of this development phase is based upon the project requirement ADO 34-11X, "Defense Navigation Satellite Techniques", and is projected as FY1977.

3. Summary of Utilization of Test Ranges by the TIMATION Project

(a) Utilization in FY1967

(1) Nature and Scope of Use: The TIMATION I satellite was launched from the Western Test Range under SESP (Space Experiment Support Program). The satellite was launched as a secondary payload on another project's launch vehicle. The satellite was delivered complete, integrated with the vehicle, and launched.

(2) Funding: Launch vehicle costs were supported by SESP and only minor integration costs were necessary from the satellite experimenter.