

THE DEVELOPMENT OF THE NORTHERN SATELLITE SERVICE.*

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Abstract

Launch- and operational cost have been prohibiting factors for small satellite systems, and it is becoming clearer that a new philosophy must be adopted to accommodate the reduced budgets of such systems. This paper discusses the design of an integrated launch facility for small polar orbiting satellites and sounding rockets. It focuses on the development of a cost-effective total service for integration, launch, operation and TT&C for micro-satellites, called the Northern Satellite Service (NSS). The goal is to create a flexible service, and offer this service to the international market.

The proposed launch facility is based on the existing infrastructure of Andøya Rocket Range (ARR) (69°30'N, 16°00'E) which is the launch facility of the Norwegian Space Centre (NSC) and Esrange (67°56'N, 21°04'E). A general telemetry, tracking and control (TT&C) station located in Longyearbyen (LYR) on the island of Svalbard (78°09'N, 16°02'E) is proposed as a supplement to the Tromsø Satellite Station (TSS) (69°39'N, 18°56'E). Such a station will give 100% ground coverage for tracking of high inclination satellites.

Technical, operational, market and organizational aspects of such a service has been assessed and it has been required that the proposed service should operate commercially, based on international cooperation. A preliminary business plan has been written. A feasibility study is now conducted as joint Norwegian-Swedish project.

Keywords: Launch facility, Micro-satellites, Tracking and Control (TT&C), Launch cost, Launch vehicles.

1. Introduction

NSC together with the Swedish Space Corporation (SSC) studying the possible development of NSS. Based on existing infrastructure at ARR, TSS and Esrange, the goal is to create a low-cost and flexible service for integration, launch, operation and control of small polar orbiting satellites.

New developments in space technology have reduced the requirements traditionally associated with satellite launch facilities. Integrated components are reducing the satellite weight and thereby reducing the requirements to the launch vehicle. This opens for a reduction in the size of the launch

facility required for orbital launches. Existing sounding rocket launch facilities can thereby be used for launch of small satellites.

Consequently, the NSC has specified the requirements to a launch facility for small satellites called the Northern satellite Service, NSS. NSS' preliminary business plan describes how ARR and Esrange can be developed into an integrated launch facility that can serve both sounding rockets and small satellites. The development philosophy behind NSS is based on a maximum reuse of existing facilities, and the goal is to create a cost-effective service for dedicated launches with a minimum of new investments and administrative overhead.

2. Why the Northern satellite Service

2.1. Background

ARR is the NSC's launch facility for sounding rockets and balloons. It is located at Andøya in the northern part of Norway. The large impact area in the Norwegian Sea permits launch of up to four stage rockets. Today, a maximum impact distance of about 1900 km has been achieved. Due to few restrictions on the selection of flight trajectories, Andøya has become a cornerstone in Norwegian and international space programs. Since the first flight in 1962 more than 550 rockets and 160 scientific balloons have been launched. The overall rate of success is as high as 89.5 percent and scientists and engineers from more than 70 institutes and universities from Europe, Japan and the USA have used ARR.

Esrange is run by SSC. At Esrange, satellite operations and launching of sounding rockets and balloons are carried out in close cooperation with many international space organizations. The ESA ERS-1 station is located close by, and Esrange is routinely conducting TT&C for a number of satellites.

TSS is the NSC earth station for data reception located in Tromsø. It is serving satellites such as NOAH, ERS-1, COSPAR/SARSAT.

An earth station installation at Svalbard is included as a part of the study. This facility is important for orbit determination and satellite control.

If the current trend towards miniaturization continues, it is necessary to provide launch and operation for small satellites at lower cost. To achieve this it is necessary to develop a flexible, turn-key solution based on existing infrastructure, experience and technology. Combined with a

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simple and flexible launch vehicle available at a low cost, a service offering dedicated launches at high frequency are expected to have a market potential. The natural geographical and operational advantages characterizing existing facilities in Northern Scandinavia, made it natural for the NSC to study the development of a satellite launch and operation service based on available infrastructure.

- a presumably typical satellite configuration was used to specify data-reception and MCC requirements,
- the market study is based on third-party material and its degree of uncertainty is difficult to quantify,
- investments and revenues are based on the best available estimates, rather than on detailed specifications.

NSS shall offer its service to the small satellite market characterized by the following parameters:

- total mass of the spacecraft, including instrumentation is constrained to 225 kg,
- the S/C shall operate in high-inclination orbits at altitudes of between 300 and 1,000 km.,
- launch of the S/C shall be possible by a rocket with a total mass less than 20 tons,
- the launch vehicle shall be compatible with the specifications of the new Universal launch facility No. 3, now under construction at ARR.

Technical and operational alternatives in which services are offered from a number of facilities at different locations are suggested. The functional requirements determine which type of facility that are included. Different alternatives will require different levels of investment.

Figure 1: Location of NSS earth stations

NSS could be Europe's first launch facility for small satellites. This is expected to give market advantages and will motivate further development of the Norwegian space activities.

2.2 Definitions

NSS is designed to offer a total service covering integration, launch, operation and control of satellites. It is based on a satellite integration and launch facility called ANDSAT, in addition to facilities for satellite in-orbit operation, data reception, TT&C and mission control centre (MCC). The objective is to offer complete services to satellites in high inclination or near polar orbits. The service is based on modifications of existing infrastructure.

The following assumptions were made for the assessment study:

- a specific rocket configuration was used to specify necessary infrastructure ,

3. The NSS Objective and concept

3.1 Objective

The objective of NSS is to establish cost-effective services that can offer launch and operation of small polar orbiting satellites.

The motivation is to create a low-cost service based on existing infrastructure and thereby minimize the required investments and utilize available experience.

NSS is based on international cooperation. An agreement with the Swedish Space Corporation, in which the two agencies has agreed to evaluate a joint development of the NSS, is signed. German participation is encouraged.

The ownership model shall be based on an international joint-venture, which are given responsibility for development, marketing and operation.

Figure 2: The New Universal Launch Facility No 3

NSS shall be the first dedicated European facility for launch and operation, of small satellites.

3.2 The Concept

- The NSS will prepare and integrate solid fuel rocket motors and conduct launches, orbit positioning, operation and control of small polar orbiting satellites.
- The NSS shall become the first European satellite launch and operation facility dedicated to small satellites.
- The NSS shall utilize the NSC operational units, ARR , TSS as well as Esrangle. It will build on the activity at these stations, and a low-cost, flexible organization is a design goal.
- NSC has, if it is commercially liable, the intention to conduct launches of a small satellites four years after project initiation. and a low-cost, flexible organization is a design goal.
- NSC has, if it is commercially liable, the intention to conduct launches of a small satellites three years after project initiation.

Technology

- The NSS will be based on existing infrastructure at ARR and Esrangle. It shall utilize the new launch facility under construction.
- Available launch vehicles shall be utilized. Unnecessary development of new technology shall be avoided. Existing and well proven technology shall be used and it will cooperate with organizations that can document long experience in the field.
- The initial development of NSS shall be made through a national infrastructure program with participants from industry and governments.

Market

- The NSS shall offer launch, operation of small satellites in market segments where it has operational advantages. In addition, the service shall build on commercial advantages given by Norwegian experience and geographical location.

- The NSS is designed to minimize operational costs and should be promoted to defined users.
- The facility shall operate commercially.
- NSS is expected to open new markets for participating industry.

Organization and Ownership Models.

- Organizational models shall ensure maximum flexibility and short lead time, and an ownership structures based on international joint ventures shall be established and given responsibility for development, marketing and operation.
- Partners must be identified for important functions such as satellite production, TT&C, data reception.

Economy.

- To establish the NSS, high-risk funds are needed for the initial phase of the project. The financial basis is determined by the investments and the required business development.
- Operation is based on commercial operation. In addition, income from data reception, TT&C and MCC is included for 40% of the satellites launched.

4 Functional specification and operational alternatives

4.1 Technical solution

An Integrated Launch Service

The geographical location and the facilities already available at ARR makes it relatively easy to expand its capacity to a launch facility for small polar orbiting satellites. This will, however, not be sufficient to achieve the necessary reduction in operation cost to make the service attractive. A dedicated low-cost launch vehicle must be defined and operation cost, amounting to at least 15% of the total cost of a mission, must be reduced through other development of turn-key services. At the same time, the visibility i.e. the time a satellite can be tracked from one ground station must be maximized. A reduction in operation cost constrains the number of facilities that can be in operation, and achieving increased visibility from one station is therefore critical.

ALTERNATIVE 1	
<ul style="list-style-type: none"> • Andøya Rocket Range: <ul style="list-style-type: none"> - integration of launch vehicle and satellite - launch operation - launch and flight control • Esrangle: <ul style="list-style-type: none"> - telemetry, tracking and control (TT&C) - backup telemetry support during flight operation - launch vehicle development 	<ul style="list-style-type: none"> • Tromsø Satellite Station: <ul style="list-style-type: none"> - backup telemetry - mission control - data reception • Longyearbyen, Svalbard <ul style="list-style-type: none"> - down range - orbit positioning

Table 1: Description of one operational alternative

It is shown that it is advantageous if a small satellite service such as NSS can offer a turn-key service, covering launch vehicle and control together with TT&C and optional data reception. Integrating all services in one system will help creating an effective, minimum cost alternative.

NSC has therefore suggested to expand, together with SSC, suggests to expand the existing sounding rocket facilities at ARR to facilitate orbital launches. Based on existing infrastructure, an extensive network of earth-based stations can be made available to support this sounding rocket and satellite launch facility.

In addition to the existing facilities at Esrange and TSS, a station at Svalbard can be connected to the TSS and thereby to the global network, through a high speed link. LYR has a substantial advantage over TSS because it can provide a 100 % coverage of the passes for TT&C and data down-link for small spacecraft in high inclination orbits. This station can also be operated as an earth station, independent of the launch facility, opening for interesting commercial perspectives. Improved ground coverage of satellites in LEO is obtained by a Svalbard station, which together with its turn-key capabilities gives NSS a unique market position. If necessary, LYR could be replaced at the cost of a degree of operational flexibility, by one or more existing stations. LYR will also serve as a down range station for determination of orbit parameters.

Figure 1 shows the locations of various stations, while their respective roles are described in Table 1. Preliminary range safety analysis indicate that it is possible to conduct orbital launches from ARR. The analysis also show that nominal azimuth is 270°-345° allowing for example sun-synchronous orbits of 750 km with inclination of 95°. Assessments of the ground coverage for a satellite orbiting at an altitude of 560 km, show that LYR, unlike other existing stations, would be able to cover all passes of a satellite in polar orbit.

Figure 3: Earth coverage for satellites at an altitude of 560 km, 5° elevation.

4.2 Possible launch scenario

Functional relationship.

As an example of the NSS operation, consider a group of stations located at ARR, Esrange, and LYR. There are a number of ways the internal, functional relationship between these stations can be organized.

ARR will be the launch facility having all necessary equipment for launch vehicle and spacecraft integration, testing, as well as launch. ARR also has the launch- and

Figure 4. A Possible Launch Scenario.

flight control responsibilities. It is monitoring and tracking the launch vehicle and it is receiving for payload and housekeeping telemetry data.

Esrange is equipped as the TT&C station. It is responsible for spacecraft TT&C after orbit injection, and it can also offer on-orbit operation if required. It will also be used as a supplement during the launch phase.

LYR will be the main down range station. This station is responsible for orbit determination and the initial tracking of the payload after separation. The tracking will use an active pointing and slant range system. If one assumes that there are no backup stations available, the reliability of LYR during launch is crucial and should be ensured by equipment redundancy. The chance of "loosing" the satellite due to insufficient orbital data is reduced if a backup station in northern Canada or Alaska is included.

A station at LYR will be able to determine the position at separation with reasonable precision. Simulations show then that 180 sec is available to monitor the orbital trajectory. Orbital parameters may then be calculated with sufficient precision to allow acquisition even at the next orbit. The advantage of LYR is its geographical location directly North of ARR, and its capability to cover all passes (i.e. it can see over the North Pole).

LYR can also in a phase 2, be equipped as a general purpose data receiving station. Given that reliable communications of sufficient capacity are available, it is possible to design the station for routine operation even without 24 hours staffing. This will exploit its potential as a unique receiving station with 100 % ground coverage.

TSS and Esrange are also available as a data receiving station for the payload during the last part of the launch and later orbits. It may act as a backup for ARR by receiving telemetry during launch. The combined coverage of TSS and LYR should provide very long continuous tracks during many passes. The location of the MCC is not restricted to either one of the earth stations. It can in principle be located anywhere, provided that communications to TT&C stations are available.

The Nominal Orbit.

To determine the flight pattern, the inclination of the satellite is a key parameter. If a 95° inclined sun-synchronous, circular orbit at 560 km is assumed, the first orbit will proceed over western Canada, then directly over Hawaii and western Pacific. The satellite is later accessible from southern Africa, passes central Europe, and is visible from all of NSS Earth stations.

After one orbit, the next pass over Esrangle last 5 minutes with maximum elevation 13°. L.Y.R. will see 8 minutes with maximum elevation 18°. For the next orbit Esrangle is not able to see the satellite, while L.Y.R. gets 5 minutes up to 8° elevation. Thereafter the satellite is not accessible from Esrangle for several orbits, while L.Y.R. gets 100 % coverage of the number of passes. The available time per day may be more than twice that of TSS for the 300 km orbit, and up to 50 % more than TSS of a 560 km orbit.

Operational Relationships.

In this scenario, ARR will have full responsibility for monitoring, tracking and telemetry from the launch vehicle and for receiving payload housekeeping data for the launch phase until the point of payload separation. In the same period TSS and Esrangle may provide backup functions, having nearly the same coverage as ARR.

Tracking of the launch vehicle is based on the active pointing and slant range measurements. Slant range is based on measurements of time delay for code transmitted through the command/telemetry chain to the launch vehicle or the payload. From pointing angles and Doppler shift velocity and position can be calculated. A tracking radar for first stage tracking is considered for safety reasons for ARR, but it is necessarily required.

L.Y.R. will handle all payload tracking and telemetry functions during last part of launch, with possible backup from ARR or Esrangle. L.Y.R. will be the only NSS station able to track the payload after separation, and will be responsible for the determination of orbit parameters. When the satellite is lost from L.Y.R., there is a gap of 170 sec before it can be acquired at for example Fairbanks (ULA) (65°07'N 147°28'E).

This implies that the orbital parameters must be calculated during the 180 sec available for L.Y.R. after separation, with a precision that allows the Alaska earth station to find the satellite.

Esrangle shall also be responsible for on-orbit operation and basic TT&C if this is to be included in a specific.

5 Launch Vehicles and small satellites

The operation of NSS require access to a reliable low-cost launch vehicle with a capacity to place approximately 225 kg in orbit. Such a launch vehicle does not exist today. The nearest are the airborne Pegasus vehicle from Orbital Sciences Corp. and Scout from LTV. Being quoted at USD 12-14M, both these vehicles have proven to be too expensive for small scale operation such as the NSS.

The NSS team is currently considering three possible launch vehicles; The orbital Express from International Microspace, the Orbex 500 from Bristol Aerospace Ltd., and PacAstro from PacAstro. Note that the latter is a liquid fuel vehicle. All these launch vehicles have sufficient capacity, and they will not be described in detail in this paper.

6 The market and NSS market position

NSS shall operate commercially and it is important to make sure that the market exists. As a part of the assessment study the market has been assessed on the basis of available information. The results indicate that:

- there is a need for the type of service proposed, but the information provided is insufficient for accurate quantification.
- the NSS concept triggers the interest of potential users, despite the uncertainty in the market estimates.

The study includes a total of 239 suggested missions with weight less than 220 kg. The results suggest that on a global basis, 12-24 small satellites will be launched annually during the next ten years. Approximately 50% will be civilian satellites, of which 8-10 satellites are expected to be LEO communications systems.

A frequent launch service that can offer dedicated orbits is preferred, assuming that a launch facility, a launch vehicle and launch operation can be provided for a reasonable cost. Affordable cost is reported to be USD15-20 M per mission. This figure includes instrumentation, spacecraft, launch vehicle and operation and operation control. the cost of launch vehicles and launch operation become relatively more important when the total mission cost is reduced. Therefore, this cost item must be monitored carefully. Resent studies indicates it should not exceed USD 5-6 M.

7 Organizational models

NSS will be established as an international joint-venture. Responsibility for the development, management and marketing could be given to a number of companies organized as shown in Figure 6 This organization model would permit:

- national and international participation in the development and maintenance of the necessary infrastructure.

Figure 5. Suggested organization model

- the establishment of an international marketing and management organization.

The share that international interests might hold in the various companies has not been considered at this point in time. Norwegian governmental support for infrastructure development can be envisaged if inter-national participation in the project is established. It is however necessary to obtain sufficient distribution of economical risk.

Different forms of international cooperation have been evaluated, and it is recommended that NSC should accept responsibility for coordinating the task of setting up an organizational model. In the first instance, the business plan must be discussed with potential national and international collaborative partners.

One necessary precondition will be the availability of low cost satellite systems, whose suppliers could be represented in the operating company. Furthermore, strategic alliances would have to be established with other companies in order to gain access to potential markets. In particular, it is necessary to focus on spreading the risks as widely as possible through the mechanism of participants taking a share of the risks associated with this type of activity.

8 Investment requirements and revenues

Tentative estimates have been made of the investments required to upgrade existing infrastructure to meet NSS'

requirements. Given that operational costs can be kept at a competitive level, and that a low-cost reliable launch vehicle is available, the investments required would be in the region of NOK 150 million (USD 25M). In addition, operational, financial and rental cost as well as estimated income has been estimated and included in a full financial analysis. The analysis show that commercial operation can be made feasible if the investments are sponsored through external sources and the operational cost are minimized. To illustrate the effect on reduced infrastructure cost and low overhead, an example showing the sensitivity of the Internal rate of return (IRR) has been included.

9 Design approaches and development philosophies

9.1 General overview of current activities.

The NSC has currently two activities related to small satellites. They are the:

- Possible development of the Northern Satellite Service,
- Emerging interest for a national/bilateral small satellite program.

The development and operation of NSS is briefly described in this paper. In addition, there is a growing interest for small satellite systems in parts of the Norwegian space science community. Norwegian governmental institutions such as NSC and the Norwegian research council (NAVF), will coordinate and support the initial work directed towards the possible formation of a national or multilateral satellite program.

Figure 6. Internal Rate of Return

9.2 Specific measures for small systems

It is our strong belief that the main success criterion for a small satellite system is cost reduction and flexibility. If the cost can be maintained at a minimum level, it is expected that small satellite will gain prominence over the next few years.

It is important to note that cost-effective operation must be applied to all aspects of a satellite mission, i.e.:

- spacecraft development (platform),
- payload development and integration,
- launch vehicle, testing and launch operation,
- in-orbit operation.

The distribution among the various items is shown in figure 8. The NSC has focused on the launch and operation of small satellites, and again the key issue is the total cost of the launch vehicle. It is necessary to identify a reliable launch vehicle that can offer launch services for a price as low as USD15-20,000 per kg.

In NSC opinion, a design approach focusing on the following items represents the most important specific measures that can be used to reduce the cost of a small mission:

Figure 7. Cost distribution of small mission, Total cost estimated to USD15M.

- use existing hardware and technology to reduce development cost for launch vehicle, spacecraft and payload,
- use modern, state of the art technology to reduce weight and power consumption,
- apply an integrated design approach for spacecraft and payload to remove redundant structures and reduce weight,
- allow higher risk due to lower program cost and reduce general testing,
- use selective product assurance,
- single (few) scientific objectives, one PI per mission,
- integrated project organizations with general knowledge to reduce the size and turn/around time for project management.

At least two alternative planning approaches are present for satellite systems. For large platforms, economy and mission objectives are the most important. For smaller systems, however, functionality and size/complexity is playing a more important role. It is therefore important not to apply the same design approaches to a small satellite system as for larger platform. Today, the launch vehicle is the critical component and this will not change until a new vehicle configuration has had a few successful launches.

9.3 Development philosophies

The design philosophy behind NSS is based on cost-effectiveness, cost reduction and flexible operation. If the expected trend towards miniaturization continues, it is necessary to provide launch and operation for small satellites at a reasonable cost. To achieve this, it is necessary to develop a:

- flexible, turn-key solution,
- service based on existing infrastructure, experience and technology,
- mission suitability through dedicated launches and launch vehicle with high flight frequency,
- service that utilize geographical and operational advantages,
- service dedicated to specific users and market niches,

- low cost launch service, including launch vehicle,
- service with an affordable mission cost (including launch cost to orbit),
- short implementation time,
- standardized satellite bus,
- simple planning methodology and small infrastructure,
- simple technical and management organization.

10. Concluding remarks

The Norwegian Space Centre is together with the Swedish Space Corporation investigating the possible development of an integrated service for launch and operation of small polar orbiting satellites, called the Northern Satellite service. Preliminary technical and operational studies show that it is feasible to establish such a service based on existing infrastructure at the Andøya Rocket Range and Esrange.

A market assessment show that there are interest in the market for the proposed service. It is not possible, based on certain market development scenarios, to invest and operate the facility on commercial terms, but if national sources support development of necessary infrastructure upgrade, commercial operation can be achieved. The Norwegian Space Centre is currently seeking partners for a joint-venture with the objective to develop and market this service.

An expanded feasibility study and a functional requirement specification is now under way. The results will be presented in November 1992.

In the design of the Northern Satellite Service, a small system philosophy been an important design goal. It is necessary to reduce the investments and utilize existing technology to create a flexible and low-cost service. Reduced cost and thereby simple organizational and management structures are key issues for the success of a small satellite program.

It has been shown that existing sounding rocket facilities and satellite Earth stations can be upgraded to obtain satellite launch capabilities at a modest cost. The main success criterion for a dedicated launch facility for small satellites is, however, the availability of a reliable low-cost launch vehicle.