SURVEY OF CANADIAN CAPABILITY
FOR LAUNCH SITE INSPECTIONS
PROJECT CANLAUNCH

SUBMITTED TO

DEPARTMENT OF EXTERNAL AFFAIRS

AND INTERNATIONAL TRADE

Prepared by:

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SURVEY OF CANADIAN CAPABILITY FOR LAUNCH SITE INSPECTIONS

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1.0 BACKGROUND

In 1982, at the second United Nations Special Session on Disarmament (UNSSOD II), Canada proposed that the Outer Space Treaty, which had been in force for 15 years, be reconsidered to take into account developments which had occurred in verification capability during that period. It was suggested subsequently by one of our allies that if nations such as Canada felt that they had the right to make such a proposal, perhaps they would also recognize the responsibility of determining whether or not such a treaty was verifiable. Canada agreed, and in the initial analysis it seemed clear that there were three areas in which verification might possibly occur. The first of these was verification in outer space, after the satellite has been launched. The second was at the space vehicle launch facility itself, immediately prior to launch. The third was on the production line and upstream.

The PAXSAT "A" series of research projects undertaken by Spar Aerospace addressed the first possibility. These projects provided the answer that verification in the space-to-space mode was feasible, but that there would be considerable technical and design problems to overcome.

The second research area, that is the feasibility of verifying whether or not a treaty may be violated by a spacecraft using on-site inspection techniques at the launch facility is the subject of the present project, called CanLaunch. Preliminary studies undertaken by Telesat Canada and Dynacon Enterprises have looked at portions of this problem, but from different perspectives.

The third verification area, namely verification on the production line or manufacturing facility, has not yet been addressed by Canada. It is recognized that effective verification may have to involve a package of all three.

CanLaunch, the current project, follows on from the Telesat study by examining Canadian technical resources with respect to the feasibility of and participating in launch site inspections. A group of 13 experts were assembled representing the wide range of technological expertise that may be needed for such inspections.

This report describes the conduct, content and results of the CanLaunch Workshop held in Ottawa at the Four Seasons Hotel on March 7-8, 1990.

2.0 THE WORKSHOP

2.1 Participants

Participants were selected on the basis of their technical expertise, with the intention of covering as broad a range of space-related technologies as Canada can assemble. The individuals were selected from industries in several provinces (British Columbia, Saskatchewan, Manitoba, Ontario, and Quebec), the federal government and the university sector. The list of attendees appears in Appendix 1.

2.2 Program

The program took place over a period of a day and a half and included morning, afternoon and evening sessions the first day, and a morning session on the second day. The structure of the program was as follows:

- Keynote presentation by External Affairs
- Background papers by Dynacon Enterprises and Telesat Canada
- Workshop session in three groups:
  - general
  - mechanical
  - electronic
- Plenary sessions for reports and recommendations

A detailed workshop schedule appears in Appendix 2.

2.3 External Affairs Presentation

The keynote presentation was made by F. R. Cleminson, Head, Verification Research Unit, Department of External Affairs. In his remarks, he recounted the history of Canada's involvement in the Outer Space Treaty, and the approaches Canada has taken in verification, including the concepts of in-orbit (Paxsat), launch-site and production line inspections. Canada's motivation is to help prevent an arms race in outer space by developing and bringing into being a credible means of verifying that space is not becoming weaponized.

Mr. Cleminson's presentation set the theme for the workshop and laid out clear objectives to be attained. The workshop was to identify Canadian capabilities in launch-site inspection and examine the problem in some depth. It should address the question as to whether External Affairs is in a position to propose that Canada, as a middle power, join with other space-faring nations to conduct a feasibility study. Such a study would develop procedures for launch-site inspections which provide a comfortable level of confidence that the true mission of a spacecraft under inspection is "as advertised", and not a weapon under disguise. The study would lead to a mock trial at a launch-site.

The workshop thus has two objectives:

A. Establish whether it is feasible to verify that the mission of a spacecraft is "as advertised", and that the spacecraft is not a weapon in disguise.

B. If such an objective is feasible, quantify Canada's capabilities to conduct a feasibility study and mock inspection with other space-faring nations.

2.4 Dynacon Enterprises Presentation

Dr. Peter Hughes, President of Dynacon Enterprises, presented a summary of his report - "Classification and Verification of Weapons in Space". The objective of his work was to develop a methodology to evaluate the potential harmfulness of one satellite with respect to other satellites, based on quantitative criteria, calculated from verifiable data. His overall conclusion is that the methodology is "difficult, feasible and useful".

The methodology entailed a listing of 29 different "harm modes", each of which can be described by quantitative parameters and qualitative characteristics. In factory, on pad and in space verification methods can then be established for each parameter and characteristic.

Dr. Hughes proposes a numerical descriptor called the "mode harm index" that is a quantitative measure of the potential harm of which a particular spacecraft is capable, in a particular harm mode. The index ranges from zero (no harm whatever) to unity (lethal - target satellite no longer functions) to greater than zero (beyond lethal). The mode harm index can be used to rank the potential harmfulness of a spacecraft's harm modes, and for many such harm modes the index can be based on the energy deposited on the target spacecraft.

A quantitative measure of the potential overall harmfulness of a spacecraft can be derived from its individual mode harm indices. The work has concluded that it is possible to classify spacecraft according to their ability to harm other spacecraft. A summary of the Dynacon presentation is provided in Appendix 3.

2.5 Telesat Canada Presentation

Mr. Sim Simanis presented a summary of the Telesat paper entitled "Launch-Site Verification Issues", derived from a March 1988 study for the Department of External Affairs entitled "Effectiveness of Spacecraft Launch Site Inspections for Arms Control Verification", by F. R. Gubby. The paper discusses some of the problems associated with launch-site inspections in terms of the limitations intrinsic to physical examination of space hardware and the logistics implicit in launch-site operations.

The difficulties stem mainly from the technical and logistic aspects. Technical problems deal with the possible deception of the inspection team by camouflage or substitutes of hardware, the access limitations which prevent or obstruct detailed examination in the launch-site environment and the safety restrictions which preclude access during certain operations on the payload. The logistic problems arise from the considerable human resources needed to adequately cover launch operations on a global scale, given the present number of sites and launch rates, and the supporting infrastructure. The paper deals only with the issue of detecting "things which are not supposed to be there", and not with the broader issue of what constitutes a space weapon.

Mr. Simanis described the sequence of operations during a launch campaign and the tests normally conducted at the launch-site. Significant characteristics of any launch campaign include the following:

1. The payload does not stay in one place but is moved frequently at any time - day or night.

2. Facilities are widely separated and hourly changes in plan and schedule are normal.

3. The closer to launch, the lower becomes the access to and visibility of the payload, and the more hectic becomes the pace.

As launch time approaches, work schedules progress to three shifts per day. Any kind of prolonged inspections during the last few days become increasingly impractical due to the potential for launch delays and associated cost increases.

The paper examined the practical limitations to inspections and poses the question - "how can the inspector be deceived at the launch-site?". This approach raises the issue of various levels of inspection which can penetrate deeper and deeper into the details of the payload.

Telesat has proposed a system of classification of inspection levels based on the degree of visibility of, access to and prior technical information about the payload. These are:

<u>Level 0</u>
- General description of payload mission available.
- Visual inspection of exterior only.
- Inspection just prior to final encapsulation.

<u>Level 1</u>
- Limited technical data on design available.
- Visual inspection of both the exterior and interior at selected stages.
- Witnessing of selected tests, real-time review.

<u>Level 2</u>
- All technical data available.
- Visual inspection permitted any time, limited to plan.
- Witnessing of all tests and data records.

<u>Level 3</u>
- Full technical data submitted in advance.
- Unlimited visual inspection, unit/panel removal.
- Selected radiographic examination.
- 24 hour surveillance.
- Special tests at option of inspector.

Telesat's assessment is that:

- Level 0 is of no real value in ensuring against treaty violations; and
- Levels 1 and 2 would provide reasonable assurance against violation but with some possibility for circumvention; whereas
- Level 3 would virtually guarantee detection of violations.

Two areas of emerging technology will impact significantly on the ability to perform effective on-site inspections. The first is the trend toward "ship and shoot", whereby there is minimal pre-launch testing; the fully-intact payload is shipped to the launch site by jumbo cargo aircraft. Under such circumstances, a Level 3 inspection would only be possible at the manufacturing plant before the payload is sealed prior to shipping.

Secondly, horizontal take-off space vehicles are emerging where a payload could conceivably be hidden in the re-usable launch vehicle itself instead of the payload, and then transferred to the payload in flight or after landing at another airport. In addition, the implications of a possible rendezvous at an orbiting space station will need to be considered in the future.

The paper concludes that launch-site inspection is a workable concept which, at the correct level, will inhibit or disclose all but very sophisticated deceptions. Its effectiveness is dependent on four criteria:

1. Access to hardware
2. Access to design data
3. Qualifications of inspectors
4. Adequate staffing

Increased confidence would be gained from surveillance at manufacturing plants and inspection of launch vehicles as well as payloads.

A summary of the Telesat presentation is provided in Appendix 4.

3.0 WORKSHOP GROUP SESSIONS

The workshop was divided into three groups which met over a period of approximately six hours in two sessions (four hours on March 7 and two hours on March 8). The three groups were:

1. General
2. Mechanical
3. Electronic

A record of the participants and deliberations of the individual groups is contained in Appendix 5, Appendix 6, and Appendix 7. The deliberations were not exhaustive, and should be viewed as a first effort at addressing the question of whether or not launch site verification is feasible and what expertise exists in Canada to participate in any subsequent international verification exercises.

4.0 WORKSHOP GROUP FINDINGS

4.1 General Group

The conclusions reached by this group were as follows:

1. The spacecraft and the launch vehicle should be dealt with at the subsystem level where it is possible to identify Canadian expertise.

2. The only levels of inspection considered to be practical and politically acceptable are Levels 0 and 1.

3. It was asserted that Levels 0 and 1 should be supplemented for some subsystems by going beyond Level 1 or back to the assembly integration and test stage (at the integration facility or factory).

4. The group examined the specific types of data required for Level 1 spacecraft and launch vehicle inspections, the tests and events to be witnessed and the visual inspections, such as fuelling, which may be needed.

5. Following such inspections and tests, there should be 24-hour surveillance of the spacecraft and launch vehicle up to the time of launch.

6. A challenge protocol should be adopted where, at any stage of the inspection, the inspection team could challenge should an anomaly be encountered. If the explanation were unsatisfactory, the team would have the right to probe deeper to the point where the unit or subsystem in question might need to be removed for closer examination.

4.2 Mechanical Group

The conclusions reached by this group were as follows:

1. Analysis must proceed by subsystem.

2. The levels of inspection proposed by Telesat need refinement and clarification, including definitions of "interior" and "selected stages". Level redefinitions may be needed for some subsystems.

3. Level 1 is often adequate but there are important exceptions, for example, the accuracy of ACS sensors which would have a major impact on the true intent of the spacecraft. There are two alternatives - either request a higher level of inspection, or go back to the assembly, integration and test phase at the factory of integration facility.

4. The level required for verification is often independent of the mission, but there are important exceptions.

5. Suspicion that the true mission is not as stated will normally depend on the analytical results of more than one subsystem. This raises the question of how data should be combined for multiple subsystems.

6. There could be some subsystems that are more critical than others for verification, and it would be helpful if such subsystems could be identified.

7. The harm mode analysis technique is a useful tool.

8. Canadian expertise is sufficient to conduct verifications, but there are some missing skills and experience. Missing from the workshop were:
    - thermal expertise
    - structures and materials (e.g. protection against atomic oxygen)
    - mechanical Ground Support Equipment
    - Other instrumentation
    - weapons
    - nuclear power sources and warheads

   However, expertise in these areas is known to exist in Canada with the possible exception of the nuclear elements which may be available from AECL or DND.

4.3 Electronics Group

The conclusions reached by this group were:

1. There is a high level of confidence that the stated purpose can be verified at level 3. Availability of documentation is essential and prior inspection at stages of assembly is critical.

2. There is much less confidence that capability beyond that stated can be verified, even at level 3. A major, but not sole concern, is the ability to reprogram electronic functions from the ground once the satellite is in orbit.

3. The break in verification confidence lies between level 1 and level 2. This is directly related to the availability of documentation and inspection.

4. Verification at level 0 and level 1 is doubtful, even with regard to the stated purpose, let alone whether that purpose can be exceeded to the point of risk.

5. Agreement to use a hard-wired comprehensive test machine would give a great deal of confidence to verification.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions of the Workshop

The following conclusions can be drawn as a result of deliberations of three separate groups and the plenary sessions:

1. Verification analysis should proceed at the subsystem level, but there are some subsystems that are more critical for verification than others. Moreover, a process needs to be created for combining subsystem verification results, and indeed to bracket and identify the ensemble of flight opportunities possible from a single launch.

2. Inspection Levels 2 and 3 as defined in the Telesat paper were deemed to be neither politically practical nor physically convenient. Inspection Levels 0 and 1, with some exceptions were feasible for mechanical subsystems, but generally were not adequate for electronic subsystems. Moreover, very high levels of inspection (beyond Level 3) would be necessary to verify with any confidence whether or not the stated purpose of some electronic subsystems can be exceeded to the point of risk.

3. Electronic subsystems are much more difficult to verify than most mechanical subsystems because of the hidden nature of electronic circuitry, complicated by the arcane nature of controlling software.

4. If Level 1 inspection is insufficient for a particular subsystem and mission, there are three choices:

a) Redefine Level 1, specific to the subsystem and mission
b) Proceed to Level 2 or beyond
c) Go further back in the payload evolution chain to the assembly, integration and test phase (AIT).

Some AIT may occur at the launch site, but more likely it will be conducted at the factory. AIT inspection would be essential for a ship-and-shoot spacecraft.

5. Technical data for payload and launch vehicle to be used for verification should be supplied as early as possible, several months before the launch campaign commences.

6. Spacecraft and launch vehicle should be under 24-hour surveillance following verification inspections.

7. The challenge protocol has merit where an inspector could challenge any anomaly found during a regular verification inspection which would require an explanation or, if necessary, a deeper and more intrusive inspection.

8. A hard-wired comprehensive passive test machine plus passive sensors such as high sensitivity mass spectrometer and geiger counters would add confidence to the verification process.

9. The harm-mode analysis technique is a useful tool.

10. In general, Canada has the necessary capability and expertise to join other space nations in a space weapons verification exercise. This expertise does not cover all areas of technology. Missing are:

- nuclear warheads
- RTG power systems
- some aspects of altitude control systems
- some aspects of liquid propellant rocket engines and thrusters.

Some of these areas may be covered within DND, AECL or the universities, but are not known to the participants of the workshop.

5.2 Objectives Achievement

The above conclusions lead to the following general statements that address the specific objectives of the CanLaunch workshop:

A. Working on the assumption that inspection beyond the Telesat Level 1 is not practical, the workshop concluded that verification is not feasible, unless inspections can intrude beyond Level 1 for some subsystem, and unless inspections can be carried out at the assembly, integration and test phase which is likely to occur before the launch campaign at the factory or integration facility.

B. Canada has sufficient capability and expertise that External Affairs can, with confidence, propose a joint feasibility study and mock inspection with another space power subject to the conditions cited in A above. Canada's shortages are in areas that can readily be supplemented by a country with nuclear weapons and launch vehicle capabilities.

Such a feasibility study would require a Canadian contingent slightly larger than the number attending the workshop, in order to accommodate the required range of technologies. It is our view that the team should comprise approximately 15 Canadian experts as follows:

1. Verification specialist (team leader)
2. Launch range systems
3. Propulsion and performance
4. Power systems - solar and chemical
5. Computers and software
6. Test and ground support equipment
7. Communications, TT and C
8. Antennas and microwave sensors
9. Instruments and optical sensors
10. Radar and remote sensing
11. Attitude Control Systems - sensors, actuators, control
12. Thermal systems
13. Structures and materials
14. Spacecraft dynamics
15. Nuclear power and possibly warheads

The above expertise can be found in Canadian industrial, government and university organizations as illustrated through the examples identified by the working groups.

5.3 Recommendations

The conclusions arrived at by the participants suggest that Canada technologically is as capable as any other space power to perform launch site verification activities. It can participate as an equal partner. Therefore it is recommended that the Department of External Affairs:

1. **Use the results of the CanLaunch workshop as evidence of Canada's ability to contribute to the elimination of weapons in space through verification by launch site inspections.**

2. **Move with confidence toward a joint pre-launch inspection feasibility study with another space power, including mock inspections.**

APPENDIX 1

ATTENDEES AT CANLAUNCH WORKSHOP MARCH 7 AND 8, 1990

Name	Affiliation	Field of Space Technology
Bill Davidson	Sciex, Thornhill, Ont.	ultrasensitive mass spectrometry
Ivan Flockton	Telesat Canada, Ottawa	launch range systems specialist
Peter Hughes	Dynacon Enterprise and University of Toronto Institute for Aerospace Studies, North York	spacecraft dynamics and attitude control
Barry Jones	Bristol Aerospace Winnipeg, Manitoba	propulsion specialist
Kris Karia	Spar RMSD North York, Ontario	solar array specialist
John MacDonald	MacDonald Dettwiler & Assoc. Richmond, B.C.	computers, remote sensing, instruments
Brent McConnell	SED Systems Saskatoon, Saskatchewan	spacecraft testing
Freleigh Osborne	Spar, St. Anne Quebec	communications, systems

Tony Raab	Canadian Astronautics Ltd. Ottawa, Ontario	antenna specialist
Harold Raine	Canadian Astronautics Ltd. Ottawa, Ontario	spacecraft integration
Sim Simanis	Telesat Canada Ottawa, Ontario	co-author, Telesat Study
Karl Snider	MacDonald Dettwiler & Assoc. Ottawa, Ontario	software
Keith Raney	Canadian Space Agency	radar specialist
Philip Lapp	Philip A. Lapp Ltd.	workshop organizer
John Keys	Philip A. Lapp Ltd.	workshop rapporteur
Peter Mueller	Philip A. Lapp Ltd.	workshop rapporteur
Ron Cleminson	Dept. of External Affairs & International Trade	
Alan Crawford	"	
Gordon Vachon	"	
Jeff Stacey	"	
Chris Tucker	Department of National Defence	

APPENDIX 2

WORKSHOP AGENDA

Wednesday, March 7, 1990

9:00 a.m.	Welcome and Introductions
10:00 a.m.	External Affairs Presentation
10:45 a.m.	Coffee
11:00 a.m.	Dynacon - Peter Hughes
11:30 a.m.	Telesat - Sim Simanis
12:00	Instructions to Workshop Groups
12:30 p.m.	Lunch
1:30 p.m.	Workshop Group Sessions (General, Electronic, Mechanical)
5:00 p.m.	Break for Dinner
6:30 p.m.	Cash Bar before Dinner
7:00 p.m.	Dinner
8:30 p.m.	Plenary Session
10:00 p.m.	Hospitality Room

Thursday, March 8, 1990

9:00 a.m.	Workshop Group Sessions
11:00 a.m.	Plenary Session
12:30 p.m.	Lunch
2:00 p.m.	Reassemble Plenary if necessary
3:00 p.m.	Workshop terminates

APPENDIX 3

DYNACON ENTERPRISES PRESENTATION

Classification and Verification of Weapons in Space

Peter C. Hughes, Kieran A. Carroll and Wayne G. Sincarsin

Dynacon Enterprises Ltd

Downsview, Ontario

Canada

Presented at the

CanLaunch

Symposium

Four Seasons Hotel

Ottawa, Ontario

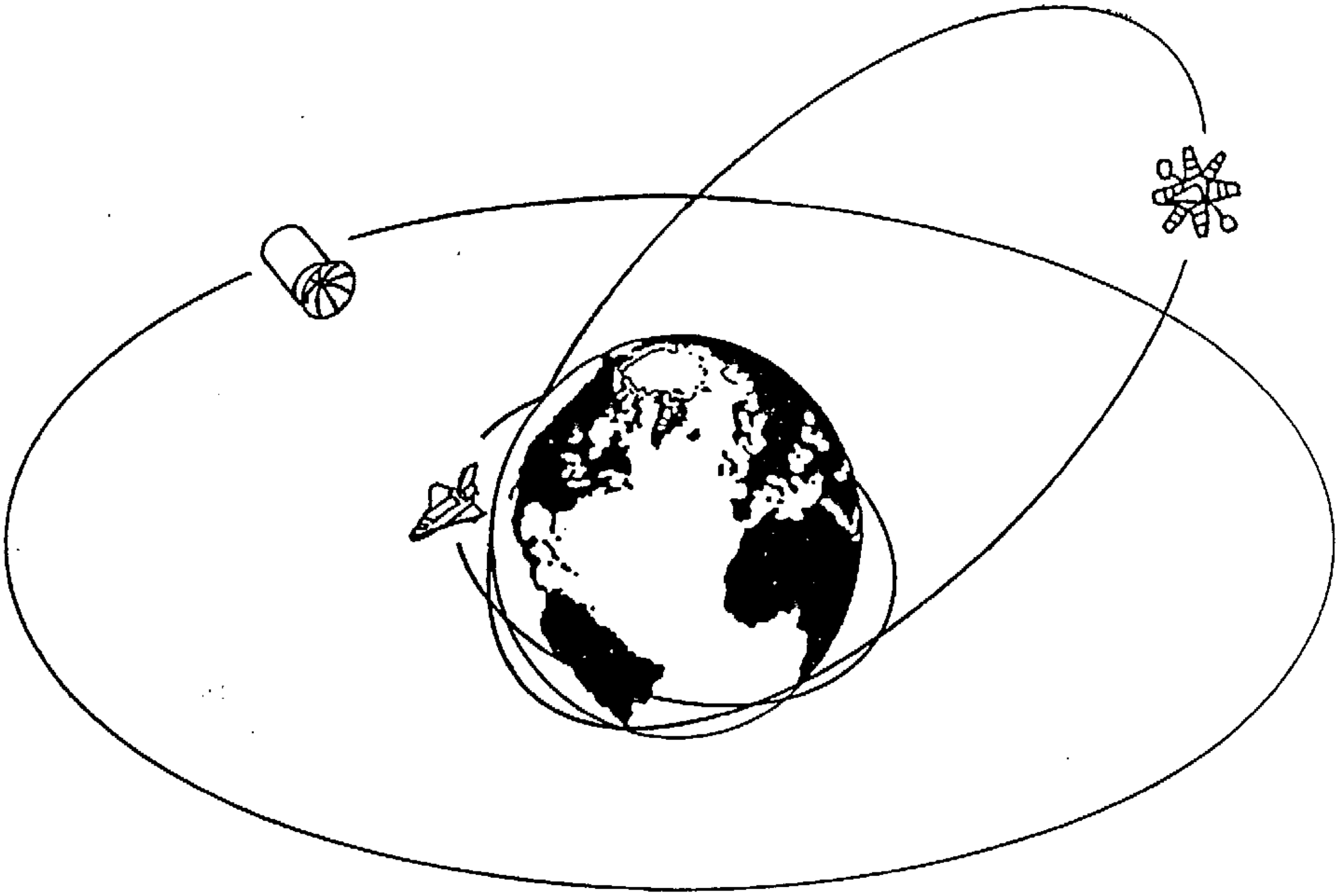
7–8 March 1990

Acknowledgments

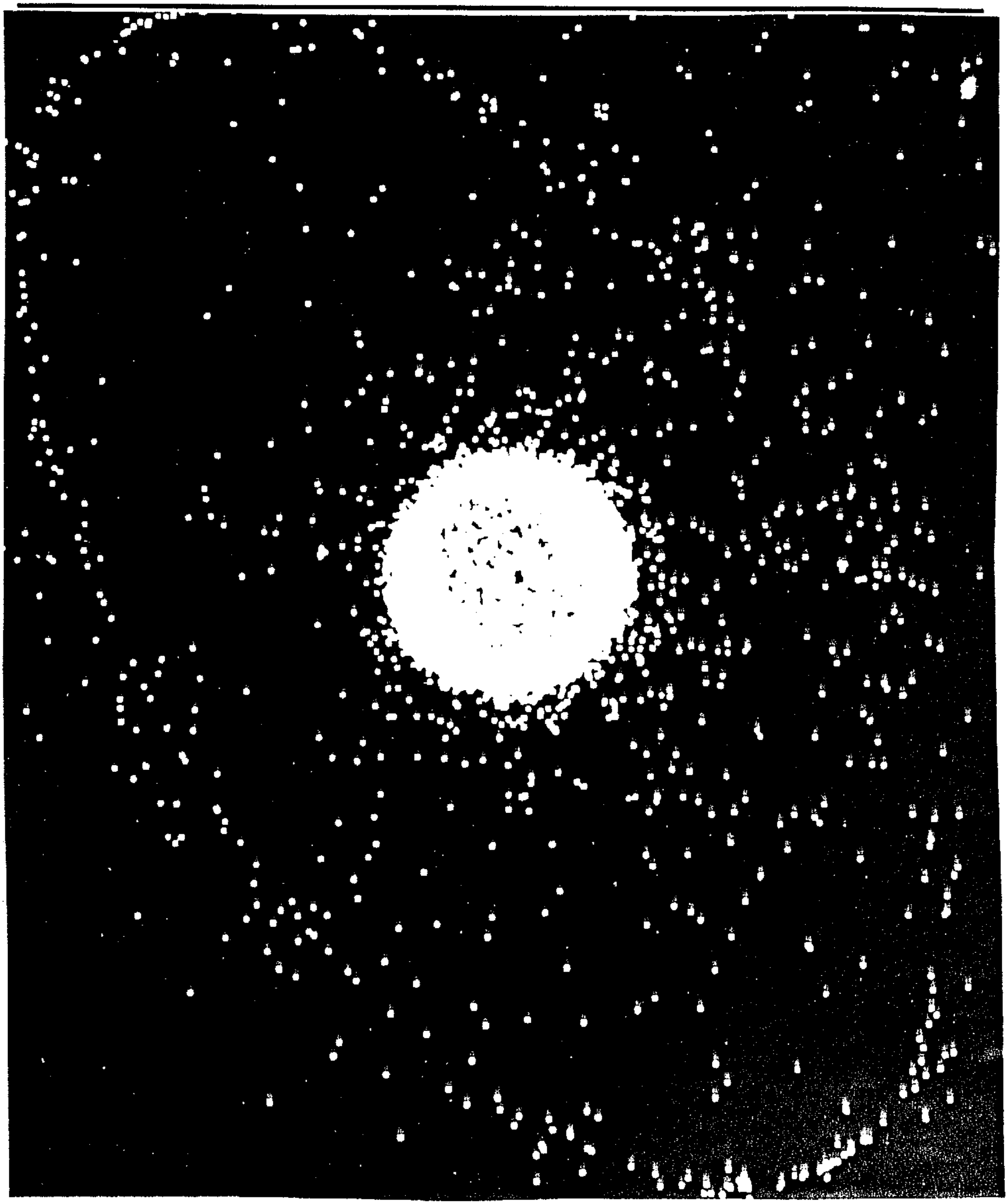
This paper is based on work carried out for the

Verification Research Unit
Arms Control and Disarmament Division
External Affairs Canada

Many Kinds of "Spacecraft"



The 6194 Objects Orbiting Within $7r_E$



Overall Objective

TO DEVELOP A METHODOLOGY
TO EVALUATE THE POTENTIAL HARMFULNESS
OF ONE SATELLITE w. r. t. OTHER SATELLITES,
BASED ON QUANTITATIVE CRITERIA,
CALCULATED FROM VERIFIABLE DATA

Three Viewpoints:

"Highly Pessimistic" ... "It can't be done."
"Highly Casual" .... "It's quite simple."

"Our View" .... **"Difficult, Feasible, Useful."**

Questions Addressed

- How might one spacecraft ***harm*** another?

- What are the ***characteristics*** of harmful spacecraft?

- How can a spacecraft's ***range of harmfulness*** be determined?

- How can spacecraft be ***ranked*** by their harmfulness?

- How can this ranking be ***verified***?

Five Major Work Stages Required

- Concept Development
- Mathematical Analysis
- Software Development
- Targeted Computation
- Evaluation and Recommendation.

Overview of Methodology

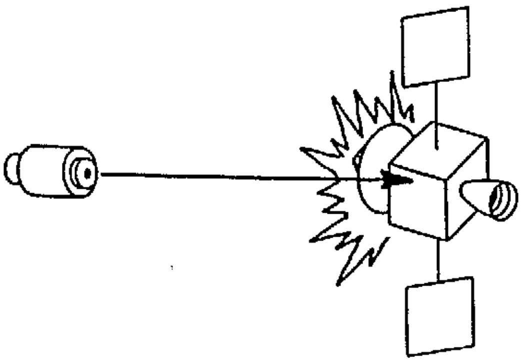
	Definition & Characterization	*Measurement of Harmfulness*	*Methods of Verification*
Spacecraft Harm	⊕ ⇓	⊕ ⇑	⊕ ⇑
Modal Harm	⇓ ⊕ ⇓	⇑ ⊕ ⇑	⇑ ⊕ ⇑
Parameters, Characteristics & Critical Capabilities	⇓ ⊕ ⇒⇒	⇑ ⇒⇒ ⊕ ⇒⇒	⇑ ⇒⇒ ⊕

List of Harm Modes Studied

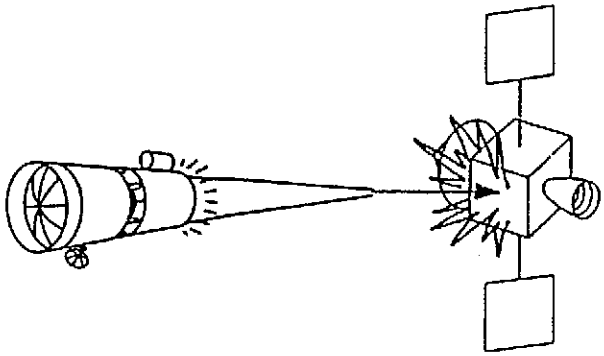
Class	Designator	Descriptor
Kinetic Energy K	K1	Ramming
	K2	Shooting
	K3	Mining
	K4	Torpedoing
Directed Energy D	D1	Blinding
	D2	Shocking
	D3	Beaming
	D4	Heating
	D5	Overloading
	D6	Blasting
	D7	Irradiating
Nuclear N	N1	Pulsing
	N2	Blasting
	N3	Irradiating
	N4	Heating
Electronic/Optical Interference I	I1	Blocking
	I2	Jamming
	I3	Spoofing
	I4	Takeover
Sabotage S	S1	Breaking
	S2	Coating
	S3	Spraying
	S4	Torching
	S5	Shading
	S6	Gassing
	S7	Shocking
	S8	Grappling
	S9	Limpet Mining
	S10	Masking

Two Examples of Harm Modes:
"Ramming" and "Beaming"

Ramming



Beaming



"Parameters" and "Characteristics"
Of Each Mode of Harm

Example: The Ramming Harm Mode:

Parameters [Quantitative]:

1. *Accuracy of tracking sensors*
2. *Acceleration from thrusters*
3. *Data capacity of communications system*
4. *Velocity change available from thrusters*
5. *Capacity of on-board computer*

•
•
•

Characteristics [Qualitative]:

1. *Presence of tracking sensors*
2. *Presence of thrusters*
3. *Presence of command/communications system*
4. *Presence of on-board computer*
5. *Control system architecture suitable for intercept*

•
•
•

“Critical Capabilities”
[Clusters of Parameters and Characteristics]

- ⇒ **Maneuvering**
- ⇒ **Orienting**
- ⇒ **Navigating**
- ⇒ **Manipulating**
- ⇒ **Communicating**
- ⇒ **Controlling**
- ⇒ •
- ⇒ •
- ⇒ •

Verification Windows

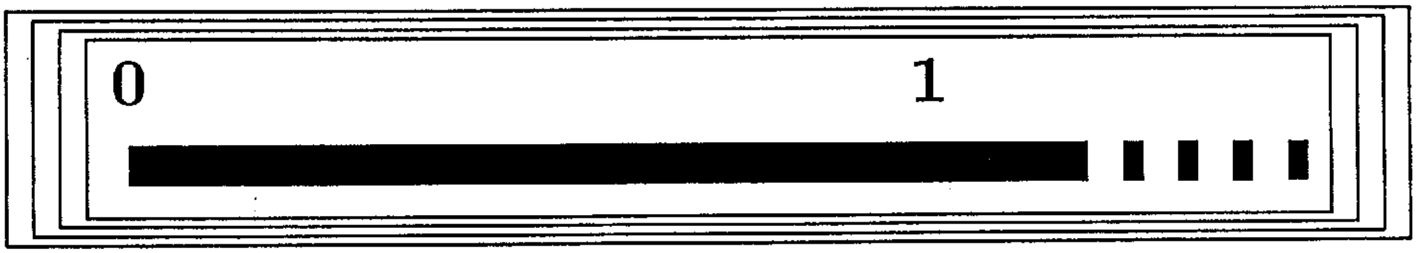
Where?	Description
In Factory	• Inspection of components • Testing of components • Observation of component-level and subsystem-level tests • Observation of spacecraft integration and testing
On Launch Pad	• Pre-launch inspection of spacecraft • Testing of fluids/gases loaded into spacecraft tanks • Observation of spacecraft fueling operations
In Orbit	• Observation of in-orbit checkout and repair operations • Monitoring of spacecraft position and velocity • Observation of spacecraft in orbit • Inspection of spacecraft in orbit

Sample Verification CheckList

Harm Mode: *Ramming*	**Verification Methods**										
	In Factory				***On Pad***			***In Space***			
Parameters	1	2	3	4	5	6	7	8	9	10	11
1	×	×	×								
2	×	×			×						
3	×	×	×							×	×
4	×	×			×	×					
5		×	×								
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Characteristics	1	2	3	4	5	6	7	8	9	10	11
1				×	×		×			×	×
2				×	×		×			×	×
3		×	×	×	×		×			×	×
4	×	×	×	×	×		×				
5			×	×	×						
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Mode Harm Index

*The "**Mode Harm Index**" is a **quantitative measure** of the **potential** harm of which a **particular spacecraft** is capable, in a **particular harm mode.***



Interpretation of Mode Harm Index:

0 : No harm whatever.

1 : Lethal. [Target satellite no longer functions.]

>1 : Beyond lethal.

Mode Harm Index (Cont'd)

Remarks on the Mode Harm Index:

1. **Motivation for the Mode Harm Index:** To rank the (potential) harmfulness of a spacecraft's harm modes.
2. **Ultimate Motivation for the Mode Harm Index:** To rank the overall (potential) harmfulness of the spacecraft.
3. Scale is open-ended.
4. For many harm modes, the mode harm index can be based on the *energy deposited onto the target spacecraft*.

Spacecraft Harm Index

*The "**Spacecraft Harm Index**" is a **quantitative measure** of the **potential** harm of which a **particular spacecraft** is capable. It is calculated from the **harm mode indices** for that particular spacecraft.*

General Form:

$$\boxed{\mathcal{H}_A = \mathcal{H}_{A_1} \oplus \mathcal{H}_{A_2} \oplus \mathcal{H}_{A_3} \oplus \cdots \oplus \mathcal{H}_{A_N}}$$

Spacecraft Harm Index (Cont'd)

Remarks on the Spacecraft Harm Index:

1. **Motivation for the Spacecraft Harm Index:** To rank the overall (potential) harmfulness of the spacecraft.

2. **Three possibilities for combining Modal Harm Indices:**

(a) Simple addition;

(b) Choose maximum modal index;

(c) Use laws of probability.

3. **Note that the Spacecraft Harm Index is based on:**

(a) Quantitative "Parameters";

(b) Qualitative "Characteristics";

(c) "Critical Capabilities".

4. **All data used must be verifiable.**

A Fundamental Symmetry

"Threat" Spacecraft		"Target" Spacecraft
This Paper.	⇔	Future Work.
How "harmful" is it?	⇔	How "shielded" is it?
What are its "harm modes"?	⇔	What are its "shield modes"?
Harm Mode Indices?	⇔	Shield Mode Indices?
Spacecraft Harm Index?	⇔	Spacecraft Shield Index?
Verification!	⇔	Verification!

Conclusions *(Greatly Distilled!)*

It is possible

to classify spacecraft

according to

their ability to harm

other spacecraft.

APPENDIX 4

TELESAT CANADA PRESENTATION

SYMPOSIUM ON SPACE WITHOUT WEAPONS
INSTITUTE AND CENTRE OF AIR AND SPACE LAW
McGILL UNIVERSITY, MONTREAL, OCTOBER 1989

E.R.Gubby, Space Programs Group, Telesat Canada

LAUNCH SITE VERIFICATION ISSUES

ABSTRACT:

Following the signing in late 1987 of a treaty between the United States of America (U.S.A.) and the Soviet Union to eliminate one class of nuclear weapons, and with the prospect of a much wider program of arms control in space being implemented during the course of the next few years, a need can be foreseen to develop routine protocols for verifying that agreed-upon restraints are being honoured by signatory nations. A key aspect of verification will be the inspection of launch vehicles and payloads at their launch sites to prevent the illicit incorporation of prohibited devices. This paper discusses some of the problems associated with such inspection, in terms of the limitations intrinsic to physical examination of space hardware, and the logistics implicit in launch site operations.

INTRODUCTION:

The idea of examining hardware destined for launch in order to verify that it is indeed what it is supposed to be, and that nothing has been added to provide some capabiliity beyond its advertised function, whether that be in terms of an overt weapon, such as a "killer" device (space mine) or a covert device, eg. for illicit surveillance, seems at first to be a simple one. The difficulty lies in the implementation of such an idea.

This difficulty stems mainly from the technical and logistic aspects. Technically we are concerned with the possible deception of the inspection team by camouflage or substitution of hardware, the access limitations which prevent or obstruct detailed examination in the launch site environment, and the safety restrictions which preclude access during certain operations on the payload. The logistic problems arise from the considerable human resources needed to adequately cover launch operations on a global scale, given the present number of sites and launch rates, and the supporting infrastructure. These aspects will be reviewed separately below.

No attempt will be made in this paper to define or categorize what might constitute a space "weapon", or to speculate on the variety of ways in which it might be employed when it gets there; only the issue of detecting "things which are not supposed to be there" will be addressed.

OVERVIEW OF LAUNCH CAMPAIGN:

The term "Launch Campaign" is used to denote the sequence of events and activities starting approximately with the arrival of the payload at the launch site and concluding with the launch. The military associations of the term are perfectly valid since it typically involves the transportation of a self-sufficient team of personnel and equipment into a remote area for some time, which team is then required to operate under high stress round the clock with critical time deadlines and severe penalties for failure to accomplish the mission (in most cases financial!).

All but the smallest payloads are shipped in several parts to permit air transportation, the constraint being the size of the aircraft cargo bay. Each part of the payload is packed in a metal shipping container, with considerable internal shock protection. A large amount of unique test equipment is also shipped, normally pre-mounted on several pallets; it may be transported by road or sea, for economical reasons. A few other parts may also be shipped separately for safety; the apogee motor, if it incorporates solid propellant, and any needed pyrotechnically-operated devices.

The sequence of operations conducted on payloads at a launch site follows a fairly well-established pattern. On arrival at the launch site, the payload and test equipment are set up in an environmentally-controlled clean room, conventionally called a "high bay". This is the first of several facilities which the payload will use on its way to the launch pad. A typical complex for non-hazardous operations can comprise several high bays with adjoining offices and workshops, and may cover some 20,000 sq.ft.

Following unpacking and re-assembly, the payload is given a thorough functional check-out, which takes several weeks. The check-out mainly concerns the electrical/electronic/RF components, but may include some tests of mechanisms, motors, etc. At this stage of the campaign the pace of operations is not too frantic, and there is usually good visibility of, and access to, all parts of the payload.

Next, the payload will be moved to a hazardous facility to load the fuel used by the stationkeeping and attitude control thrusters, and, if a liquid apogee motor is used, its bi-propellants. These operations are hazardous because of the chemical toxicity of these fluids, and because of their extremely high reactivity, with consequent risk of fire or explosion. Personnel access restrictions apply at all times in these facilities, and, during actual fueling, numbers are limited to essential personnel only, typically not more than a handful.

A further hazardous activity entails the installation of the pyrotechnics and, if used, the solid apogee motor. This may be done at a third facility, and, depending on the mission requirements, the payload may require moving to yet another facility for balancing. The final task before going to the launch pad will be the encapsulation of the payload inside the fairing, and sometimes into an integrated assembly of two or more payloads. The payload assembly is then installed on the launch vehicle, typically slightly more than a week prior to launch.

Following each major operation, it is customary to perform an electrical functional test of the payload, to verify that no failures have developed, before proceeding to the next step. This requires a telemetry link to the test equipment which, due to its size and weight, is not readily transportable.

One might ask why all this testing is necessary, since the satellite is supposed to operate in space for years without problems? Experience has shown that a number of failures do develop during launch site payload preparation, even after rigorous environmental testing at the manufacturing plant. Some are caused by the necessary re-assembly, others by operator error, and random failures are always possible. Whatever the cause, no satellite owner would consider launching with less than a complete set of operating units, so continual checking is the norm, right down to the instant of lift-off.

Variations on the above theme can occur, eg. several hazardous operations may take place at one facility, or, a functional test may be omitted at one stage. Also, if the launch vehicle is manned, rather than expendable, there will be additional steps because the payload integration is more complicated, since the payload cannot be activated for deployment until orbit is reached, thus there are many more interfaces with the vehicle. However, several general points can be made, as follows, which are always true.

Firstly, the payload does not stay in one place at the launch site, on the contrary, it is moved around quite a lot, and can be moved at any time of the day (or quite often at night, in fact, to reduce the risk of overheating in the sun).

Secondly, the facilities are widely separated, thus close track of schedules must be maintained by anyone wishing to observe a certain activity. A change in plan while off shift can result in arriving at a recently-vacated bay, followed with possibly a thirty-minute drive to the right place. Hour-to-hour changes in plan are in fact quite normal on launch campaigns, due to the need to time-share support equipment, work around component failures, etc.

Thirdly, the closer the payload becomes to being launched, the lower becomes the access and visibility, and the more hectic becomes the pace. The work schedule typically progresses from one shift per day at the start, to three per day by launch time. Any kind of prolonged inspection in the last few days before launch would be very unfavorably regarded by the launch team; aside from the interruption, there would be a substantial cost increase associated with any launch delay.

PRACTICAL CONSIDERATIONS OF INSPECTION

This section first answers the question "what can an inspector reasonably expect to see and do during the launch campaign?". This is linked to the more general question "how can the inspector be deceived at the launch site?".

Given that the inspector has a broad familiarity with various categories of satellites, a visual examination of the exterior of a payload can immediately disclose basic inconsistencies between the actual constitution of the satellite and the required constitution as dictated by its advertised mission. This is to say, for example, that a multi-channel geosynchronous communications satellite has certain features which clearly differentiate it from an interplanetary probe or a sun-synchronous low earth orbit mapping satellite.

At the next level of inspection, still visual, provided the inspector is familiar with a certain category of satellite, he could discover an incongruity at the component level; for example a communications satellite should not contain a large imaging device. At this level, access to the interior of the payload, while not essential, would definitely improve the security of the inspection.

Going down yet another level, to a specific type, say, a Hughes HS- 376, the inspector could identify a particular unit that was non-standard compared to other models of the same type. Interior access would now be essential.

This probably represents the practical limit for visual inspection as a means of verifying conformity to a postulated role, and even this requires us to assume a breadth of knowledge on the part of the inspector which is rare in the industry. To permit individuals without this knowledge to learn the necessary details would require acquisition and distribution of design information on all extant payloads, most of which would certainly be regarded as company confidential, even if not classified. This is one of the logistic problems which would have to be solved.

It must be apparent that, even allowing for complete visual inspection, ample scope still exists for deception; for example an explosive device can easily be disguised as a standard electronic box. Thus, at least one more level of inspection would be necessary, which would have to be associated with the functional testing of the payload by the test equipment. Some form of electronic signature characterisation would be required, able to detect any discrepancy in the test results, which might then point to an illicit unit. However, this would require a substantially higher level of knowledge about the payload design, coupled with expertise in data processing soft-ware, since this would have to be generated by the inspection authority. Even then, additional safeguards will be needed to preclude the possibility of the test equipment itself providing falsified data. Since modern test techniques frequently involve software simulation of one subsystem of a satellite in order to test another, this would be quite easy to arrange.

Another possibility would be the deliberate omission of a test on that part of the hardware that was illicit to mask any deviation compared to similar types. Launching any hardware without a pre-launch functional test is obviously not acceptable in standard commercial practice, but the advantage gained by launching an illicit device may more than offset the risk of "wasting" a launch, particularly if the device is only an add-on.

CLASSIFICATION OF INSPECTION LEVELS

As part of a study carried out for the Department of External Affairs in March 1988, Telesat suggested a system of classification of inspection levels, based on the degree of visibility, access, and prior technical knowledge of the payload. This system is given below. It is felt that classification of various levels of inspection will generally facilitate future discussions on launch site inspections, and will especially simplify the definition of inspection regulations for various categories of payload.

Level 0
- General description of payload mission available
- Visual inspection of exterior only
- Inspection just prior to final encapsulation

Level 1
- Limited technical data on design available
- Visual inspection at selected stages, interior/exterior
- Witnessing of selected tests, real-time review

Level 2
- All technical data available
- Visual inspection permitted any time, limited to plan
- Witnessing of all tests, data record

Level 3
- Full technical data submitted in advance
- Unlimited visual inspection, unit/panel removal
- Selected radiographic examination
- 24-hour surveillance
- Special tests at option of inspector

At the present stage of satellite complexity and technology, our assessment of the effectivity of the above levels is as follows:

Level 1 is considered to be of no real value in ensuring against treaty violation;

Levels 1 and 2 would provide reasonable assurance against violation on most commercial and standardized military payloads; there would still be some possibility for circumvention, but only within definable limits;

Level 3 would virtually guarantee against violation; circumvention would require such sophistication as to render it very unproductive and probably unreliable.

LOGISTIC ASPECTS

The six nations currently engaged in regular launches account for between one and two hundred launches each year, although the Soviet Union's rate is about an order of magnitude higher than the others combined at present. The launch rate from the U.S.A. will increase considerably through the end of the decade, due to the re-establishment of the expendable vehicle industry. These launches occur from more than a dozen sites.

To cover one payload at a Level 3 would require a team of between six and nine inspectors. Each team could probably handle four launches per year, so a rough estimate would be between three and four hundred inspectors. This is not a large group, although with administrative support, headquarters, etc. it would probably translate to about two thousand personnel. The primary obstacle would lie in recruiting that many people already having the necessary breadth of expertise. Clearly, almost the only source would be the industry itself, as credentials of inspectors would have to be above question by all parties. However, the number could be reduced by perhaps 50% if lower level inspections were to be employed. After the initial staffing needs were satisfied, a program for recruiting and training of replacements would have to be initiated.

Huge amounts of documentation can be expected from this activity, not only from the pre-submitted design information which would be essential to allow training, but also from the inspection records, which would at least require archiving for a period of time, and should additionally be formatted to allow retrieval, cross-checking, etc. This indicates the need for a sophisticated and secure documentation library, and a data storage and processing support activity.

At the larger, more active sites, permanent office facilities for inspectorate staff would be needed. Data storage and retrieval systems, archiving, and communications networks to other sites would be required. Stringent security measures would have to be taken to ensure confidentiality of data is not compromised, and to comply with technology transfer restrictions.

LIABILITY/CONTRACTUAL CONSIDERATIONS

Some payloads will require partial dismantling, removal of panels, etc. to permit full visibility. If these operations resulted in damage to the payload, the owner/contractor might consider the inspection authority liable. Some form of blanket indemnity would need to be arranged, as the inspection authority would constitute a third party outside the coverage agreement in effect between the launch agency and its customer.

As mentioned above, the launch campaign involves maintaining a team of very highly skilled labour at a remote site, and paying a launch agency for the use of facilities which it has installed at considerable cost; the longer the campaign, the more expensive the launch. Beyond the direct costs of the launch campaign, other expenses could accrue in the event of a delay, such as loss in revenue. If the inspection authority causes an extension of the campaign by impeding or interfering with the planned payload operations, it might reasonably be held accountable for the additional expense.

NEW TECHNOLOGY IMPLICATIONS

There are two areas of emerging technology which can be expected to change the strategy and extend the scope of any launch site inspection program developed over the next few years. The first of these is the trend towards minimal pre-launch testing of payloads. This approach is being increasingly employed to reduce the costs of the launch campaign. With the availability of jumbo cargo aircraft, it has become feasible to fly even quite large payloads to the launch site fully assembled. This has in fact been possible for some time, but the extremely conservative attitude towards the methodology of space hardware testing and preparation has delayed its introduction. Clearly, any detailed interior examination of a payload would be at odds with this method. A Level 3 inspection would only be possible at the manufacturing plant, with the completed payload being shipped under seal to the launch site.

Secondly, several countries are now pursuing the development of horizontal take-off space vehicles. Runways for this category of launch vehicles may not be co-located with existing sites. At the least this would affect the logistics of an inspection program, but the strategy of inspection might be different. Since these vehicles would be re-usable, a payload could conceivably be secreted in the vehicle itself instead of in a payload. This is not a major concern on expendable vehicles because all parts except the final stage re-enter and are destroyed. Confirmation that the vehicle has indeed climbed to orbit with an inspected payload and not diverted to an un-monitored site to swap payloads might be part of the procedure.

Any treaty which is written must encompass the above possibilities. The implications of orbiting space stations also needs to be considered.

CONCLUSION

The practical limitations and logistic implications of launch site inspections for arms control verification have been discussed. A system of inspection level classification has been outlined which will facilitate the definition of inspection requirements. It has been shown that launch site inspection is a workable concept, and, if exercised at the appropriate level, will inhibit or disclose all but very sophisticated deceptions. Its effectivity is dependent on four criteria:

i) access to hardware
ii) access to design data
iii) qualifications of inspectors
iv) adequate staffing

To increase the confidence of controlling proscribed devices in space hardware, a complementary program of surveillance at manufacturing plants is recommended. Consideration should also be given to extending launch site inspections to parts of the launch vehicle. The wording of any treaty must cover anticipated changes in space transportation technology and methodology.

ACKNOWLEDGEMENTS

The author wishes to thank Mr.Alan Kidd and Mr.R.J.Shields for their valuable contributions to the development of the concepts expressed herein, and the latter for permission to use some of his material in the presentation of this paper.

APPENDIX 5

REPORT OF THE GENERAL GROUP

The General Group consisted of:

F. Osborne - Chairperson
R. Cleminson
W. Davidson
I. Flockton
H. Raine
K. Snider
J. Tracey - Rapporteur

This group was responsible for developing an overall logic for the approach to on-site inspection, using the concepts set out in the Telesat Canada study (Levels 0-3). Keeping in mind that the purpose of the exercise was to identify as closely as possible an optimal Canadian inspection team, the approach was to go through the process of a mock inspection, at each level, in order to establish the skills required.

Within the group, there were skills in launch operations, payload integration and test, software, special measurement techniques (ultrasensitive mass spectrometry) and verification issues. They were expected to provide the roadmap that would be used to guide the other specialist skill groups through the inspection logic. Ultimate payload identification, including warhead and related initiation and fusing, were within the purview of this group.

Inspection Logic

It was concluded that the spacecraft and launch vehicle should be dealt with at the major sub-system level, which was the approach also followed by the other groups. It was possible to identify Canadian expertise at the sub-system level:

a. Spacecraft

i. Payload
  - communications (Spar, Telesat)
  - remote sensing (EMR, CRC, Spar, MDA)
  - scientific (CAL, Spar, Bristol)

ii. Mechanical/Thermal (Spar,CRC, Telesat)
iii. Propulsion/Mission (Spar, Bristol, Telesat)
iv. Power (Spar, CAL, Telesat)
v. Attitude Control (CRC, Telesat, Dynacon)
vi. Systems (CRC, Telesat, Spar, CAL)
vii. Communications/Ranging/Telemetry (Spar, Telesat, SED, CAL)

b. Launch Vehicle

i. Propulsion/Mission Analysis
  - sold propellant expertise,minimal liquid propellant experience (Bristol)

ii. Third Stage Guidance System and Electronics (Litton, Sperry)
iii. For Launch Vehicle as Threat
  - the pieces that stay in orbit (Spar, Telesat)

iv. Test Equipment - EGSE/MGSE
  - mission dependent/requires mission specialist (SED, DSMA, Spar)

Inspection Levels

The only levels considered to be politically acceptable were Levels 0 and 1. Level 0 was considered by the General Group to be impractical as a means of identifying any deviation from plan (i.e. - could not verify that the mission was "as advertised"). Thus, this group addressed the possibility of modifying or supplementing Levels 0 and 1 to be more effective, but without being more intrusive.

At Level 1, there are data examination and inspection activities for both the spacecraft and launch vehicle:

a. Technical Data, Spacecraft
(should be made available to the inspection team as early as possible)

- general description of spacecraft, mission and duration
- mass, propellant and power budgets (to the unit level)
- drawings of launch and on-orbit configuration, including an exploded view or two-dimensional layout drawing at the unit level
- command and telemetry lists
- subsystem block diagrams identifying redundancies
- assembly, integration and test flow diagrams and schedules (to help identify test flow sequence)

b. Visual Inspection, Spacecraft

There needs to be visual inspection at selected stages, both interior and exterior. In order to avoid excessive intrusion at Level 1, such inspections could begin at the assembly, integration and test stage (AIT), back at the factory or integration facility (like the David Florida Laboratory). This approach extends beyond the launch site, but may be the only practical alternative to provide visual interior inspection without dismantling the spacecraft, disrupting launch operations thereby causing costly delays and potentially threatening the advertised mission. Inspection at the AIT stage is the only practical approach for those satellites that utilize the "ship and shoot" method of launch preparation. Such an approach would provide far greater confidence in the verification process.

In addition to visual inspection, it is important at Level 1 to witness selected tests:

- mass, spin balance, any AIT at launch site
- deployments for specific subsystems (antennas, solar arrays, probes, etc.)
- propellant loading and weighing

For Level 1 launch vehicle inspections, the data required would include:

- users handbook
- mass and propellant budget
- for anything that stays in orbit, details such as size, weight, fuel types and quantity, control, orientation and restart capability
- launch profile
- details of destruct system
- countdown manual

Visual inspections should include any component that stays in orbit. Such inspections of the launch vehicle should begin when the vehicle arrives at the launch site and surveillance should continue 24 hours a day until launch occurs. Included in such inspections should be stage erection and the individual fuelling operations as they occur.

Challenge Protocols

The General Group suggested a verification strategy that is worthy of further consideration. At any stage of inspection or test witnessing, if any anomaly in an observable is detected (say in weight, power consumption, volume, etc.) compared with what would be expected for the declared mission, then an explanation would be required. If the explanation is unsatisfactory, it would be challenged and the inspector would have the right to probe deeper. For example, he/she could progress through the following stages:

- unit level block diagrams
- unit level assembly diagrams
- a deeper visual inspection of the spacecraft
- removal of the unit in question from the spacecraft for more detailed inspection (e.g. x-ray, dismantling, special measurements with special detectors, etc.)

Warheads

The General Group had no special skills in warheads, initiation or fusing and suggested that such expertise most likely would be found within DND. Since this workshop was unclassified, the subject was not explored further.

Conclusions of the General Group

1. The spacecraft and the launch vehicle should be dealt with at the subsystem level where it is possible to identify Canadian expertise.

2. The only levels of inspection considered to be practical and politically acceptable are Levels 0 and 1.

3. It was asserted that Levels 0 and 1 should be supplemented for some subsystems by going beyond Level 1 or back to the assembly integration and test stage (at the integration facility or factory).

4. The group examined the specific types of data required for Level 1 spacecraft and launch vehicle inspections, the tests and events to be witnessed and the visual inspections, such as fuelling, which may be needed.

5. Following such inspections and tests, there should be 24-hour surveillance of the spacecraft and launch vehicle up to the time of launch.

6. A challenge protocol should be adopted where, at any stage of the inspection, the inspection team could challenge should an anomaly be encountered. If the explanation were unsatisfactory, the team would have the right to probe deeper to the point where the unit or subsystem in question might need to be removed for closer examination.

APPENDIX 6

REPORT OF THE MECHANICAL GROUP

The Mechanical Group consisted of:

P. Hughes - Chairperson
B. Jones
K. Karia
S. Simanis
G. Vachon
P. Mueller - Rapporteur

Mechanical skills represented in this group included propulsion and performance, attitude and orbit control, power supply (solar arrays and other sources), mechanisms and mechanical ground support equipment (MGSE). It concentrated on those inspection skills needed to assess the mechanical characteristics of the rocket and payload. It was anticipated that, from estimated weight, thrust and duration of each stage, it might be possible to bracket the weight and orbit elements of the spacecraft, and that at a certain level of inspection, it should be possible to estimate orbital and attitude manoeuvrability, and the kinetic potential of the vehicle. An external examination of the solar array structure may yield an estimate of electrical power consumption. External mechanisms and MGSE may provide further insight as to the mission of the spacecraft.

The group came to the early conclusion that the analysis must proceed by subsystem. For each subsystem, a set of questions concerning verification was developed, the answers to which were occasionally found to differ depending on the spacecraft mission or type of satellite. Thus, a matrix was created, made up of 20 rows (subsystem) and 12 columns.(types-of-satellite).

The types of satellites identified were:

1. Communication - GEO
2. Communication - 12 Hour
3. Communication - LEO
4. Navigation - GPS/GLONASS orbit (medium altitude)
5. Navigation - GEO
6. Earth Observation - Optical
7. Earth Observation - Radar
8. Earth Observation - Meteorological
9. Industrial Processing
10. Unmanned Platforms
11. Manned Platforms

12. Scientific Experiments

Typical types of subsystems identified were:

a. Propulsion - Primary (apogee motor, major thrusters)
b. Propulsion - Secondary (vernier, thrusters, station keeping, ACS)
c. Re-entry
d. Communications Antennas
e. Energy Reflectors
f. Power - Photovoltaic
g. Power - Radioisotope Thermionic Generators (RTGs)
h. Power - Solar Heat Engine
i. Energy Storage - Batteries
j. Fission Reactor
k. Passive Thermal Control
l. Active Thermal Control
m. Attitude Sensors
n. Other Sensors
o. Radiation Shield
p. Atomic Oxygen Shield
q. Bus Structure
r. Other Instrumentation
s. Warhead

The above lists are not complete, and are intended to illustrate an analysis technique, not the analysis itself.

For each intersection of the matrix, the following questions were asked:

I. Is the subsystem required?
II. Will the subsystem be tested at the launch site?
III. What level of verification is needed?
IV. Does a Canadian capability exist for this area of technology?
V. Miscellaneous expert questions that address whether or not performance or function claimed is reasonable - expertise required is very subsystem and mission dependent.

The group tested one column of the matrix for a communications GEO satellite. The following were the results:

Questions

Sub-Systems		I	II	III	IV
	a	Y	1.5	Y	Y
	b	Y	Y	1.5	Y
	c	N	N/A	1	Y
	d	Y	?	1	Y
	e	N	N/A	1	Y
	f	Y	?	0.5	Y
	g	N	N/A	1.5	N
	h	N	N/A	0	Y
	i	Y	Y	1	Y
	j	N	N/A	0.5	Y
		...and so on...			

In many instances, the answers to the questions were not dependent on the type of satellite, for example, launch vehicle propulsion. The group analyzed the first 10 subsystems (a to j) to gain some confidence that the analyses technique was valid, but it did become evident that a new definition of inspection level may have to be spelled out for certain subsystems.

Conclusions of the Mechanical Group

1. Analysis must proceed by subsystem.

2. The levels of inspection proposed by Telesat need refinement and clarification, including definitions of "interior" and "selected stages". Level redefinitions may be needed for some subsystems.

3. Level 1 is often adequate but there are important exceptions, for example, the accuracy of ACS sensors which would have a major impact on the true intent of the spacecraft. There are two alternatives - either request a higher level of inspection, or go back to the assembly, integration and test phase at the factory of integration facility.

4. The level required for verification is often independent of the mission, but there are important exceptions.

5. Suspicion that the true mission is not as stated will normally depend on the analytical results of more than one subsystem. This raises the question of how data should be combined for multiple subsystems.

6. There could be come subsystems that are more critical than others for verification, and it would be helpful if such subsystems could be identified.

7. The harm mode analysis technique is a useful tool.

8. Canadian expertise is sufficient to conduct verifications, but there are some missing skills and experience. Missing from the workshop were:

    - thermal expertise
    - structures and materials (e.g. protection against atomic oxygen)
    - mechanical Ground Support Equipment
    - other instrumentation
    - weapons
    - nuclear power sources and warheads

   However, expertise in these areas is known to exist in Canada with the possible exception of the nuclear elements which may be available from AECL or DND.

APPENDIX 7

REPORT OF THE ELECTRONICS GROUP

The electronic group consisted of:

J. MacDonald - Chairperson
A. Crawford (part time)
B. McConnell
A. Raab
K. Raney
C. Tucker
J. Keys - Rapporteur

This group was concerned with the major systems and subsystems of the payload. The skills included computers, antennas, instrumentation, communications, radar, test procedures in-flight and pre-launch, and electrical ground support equipment (EGSE). The group was to focus on ways, at each level of inspection, to determine or verify the specific mission of the electronic systems on-board, and thus evolve an inventory of the skills needed for such inspections.

It should be possible from an examination of radiators and associated waveguides on the spacecraft to establish the purpose, wavelength and possibly the power of the emitters (communication, telemetry, radar, etc.). Access to software, storage and processing capacities may provide further insights on payload missions. Analysis of test procedures at pre-launch, LEOP and operational phases may be particularly revealing.

Method of Approach

The electronics group adopted the following procedure in order to arrive at a judgement as to whether or not the electronic systems of a satellite are constructed to carry out the stated purpose:

- the electronic systems to be considered during the working sessions were identified.
- each system was evaluated against the 4-level Telesat verification framework.
- two criteria were defined to rate the systems for each level of verification:

Criterion A: The extent to which the electronic system is deemed to meet the stated purpose; the system is rated a 10 if there is confidence that verification is possible, a zero is given if there is no confidence.

Criterion B: The extent to which the electronic system could exceed the stated purpose to the point of risk; the system is rate a 10 if there is little chance that the stated purpose could be exceeded; a o is given if there is flexibility to the point of risk.

- the electronic systems were then rated by each member of the group and independently, followed by a consensus-forming discussion.
- the group then ranked the electronic systems against the criteria. The results are presented below.
- conclusions were drawn based on the results of the rating and ranking exercises.
- finally the group identified individuals and/or organizations that have the expert knowledge to make competent verification assessments. They are listed below.

Results

The rating process described above led to the following matrix:

	Verification Level							
	3		2		1		0	
Electronic Systems	A	B	A	B	A	B	A	B
Active microwave sensors*	9	8-3	8	6-3	6	3	3	2
Active optical sensors*	8	6	7	5	4	2	2	1
Passive sensors	8	9	7	6	4	3	2	1
Comms - transmit*	9[1]	8-4	7	5-4	5	3	3	2
Communications - receive	9	8	7	6	5	3	3	2
Computers + software*	8	2	7	1	4	0	0	0
ACS - sensors	9	7[2]	8	6[2]	5	3	3	1
ACS - activators	9	7[3]	8	6[3]	5	3	3	1
ACS - control	8	4	7	3	4	1	2	0
Power - solar	10	9	9	8	7	5	5	4
Power - nuclear*	10	7[4]	8	4	7	3	3	1
Power - chemical*	9	8	8	7	6	4	4	2
TT & C	9	6	8	5	5	2	3	1
Existing GSE*	9	6	8	3	6	2	2	0

* electronic systems for which the consequence of error in verification can be serious.

Notes:
1. A 10 if pure non-programmable microwave.
2. Less verifiable if a StarTracker.
3. Reduces to a 4 for a magnatorque.
4. Consult AECL/AECB.

Organizations and individuals that were identified by the group are listed in the following table:

Canadian Experts

Area	Institution	Individual
Microwave sensors	Litton	
	CCRS	Raney
	CAL	Raab
	MDA	
	ComDev	
	SPAR	
	MPB	
	DREV	
		Deane
		Livingston
Active optical sensors	Lumonics	
	OPTECH	
	MPB	
	DREV	
Passive EM sensors	MPB	
	SPAR	
	CAL	Gore, Raab
	CREO	Gelbart
Communications and TT & C	SPAR	Hing
	CAL	Raab
	ComDev	Kudsia
	SED	Grant
	MPB	Huntley
	Telesat	Leadley
		Keyes
Computers and S/W	MDA	MacDonald
		Snider
	SED	Baillie
	CAL	
	NRCC	
	SPAR	
	ComDev	
Attitude control systems	SPAR	Moore
		Staley
	CAL	Hershom

Power	CAL AECL AECB SPAR SCIEX	Raine Davidson Ballard
GSE	SED SPAR Telesat Marconi DFL	McConnell Garside
Special GSE	The above plus DREO Barringer AECL SCIEX	

Note: The composition of the verification team will depend upon the electronic systems to be verified.

Conclusions of the Electronics Group

1. There is a high level of confidence that the stated purpose can be verified at level 3. Availability of documentation is essential and prior inspection at stages of assembly is critical.

2. There is much less confidence that capability beyond that stated can be verified, even at level 3. A major, but not sole concern, is the ability to reprogram electronic functions from the ground once the satellite is in orbit.

3. The break in verification confidence lies between level 1 and level 2. This is directly related to the availability of documentation and inspection.

4. Verification at level 0 and level 1 is doubtful, even with regard to the stated purpose, let alone whether that purpose can be exceeded to the point of risk.

5. Agreement to use a hard-wired comprehensive test machine would give a great deal of confidence to verification.