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Caution Light: The Anik E2 Solar Disruption And Its Effect On Telesat Canada

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CAUTION LIGHT: THE ANIK E2 SOLAR DISRUPTION
AND ITS EFFECT ON TELESAT CANADA

by

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This thesis, submitted by Elizabeth Howell in partial fulfillment of the requirements for the Degree of Master of Science, Space Studies from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the Graduate School at the University of North Dakota and is hereby approved.

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A decade ago, in a Canadian suburb far, far away from Grand Forks, I discovered there was a graduate distance degree available in Space Studies that would let me stay close to my home while pursuing my passion. My young age and subsequent life circumstances prevented me from starting until 2010. It has been a privilege in the two years since then.

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who learned first-hand about the effects of radiation in space.

ABSTRACT

Telesat Canada is a satellite communications firm, founded in 1969, that provides global broadcast and broadband services. Its fleet of satellites includes the geostationary Anik line. On January 20, 1994, a major solar storm knocked out communications on two Anik satellites. Anik E1 was recovered through a backup system within hours. However, Anik E2 was non-operational until June 31, 1994, when engineers used an innovative ground fix to regain control.

This thesis proposes to trace what happened to Anik E2 and its effect on Canada's broadcast industry. It will act as a case study for the implications for satellite companies looking to gird themselves against the effects of solar storms. The aim is to provide a comprehensive overview of what was learned from the near-loss of Anik E2 and to provide information for broadcast professionals, satellite technicians and policy makers concerning what to do should a similar incident happen again.

CHAPTER I: INTRODUCTION

Although the Sun's light gives life, warmth and energy to Planet Earth, there is little reason to think of that in Ottawa in January. The Canadian city becomes a frustrating mix of freezing rain, snowstorms, temperatures as low as minus 40 degrees Celsius (or Fahrenheit, if one uses that scale), and long nights full of cold stars. At that time of year, the best protection against the elements is a spacesuit, one may conclude in a bitter 6 a.m. moment prior to taking the bus to work. There is just too little sun to light and warm the way at 45 degrees north latitude at the beginning of the year.

There's a satellite operator in Ottawa, though, that would speak differently about the sun's power in January. On the eastern edge of the city, with a view of a transit station tunnel on one side and Pineview Golf Course on another, sits the Telesat campus. The company provides broadcast services to millions of people across most of the world. More than a dozen of its satellites (Telesat, 2012a) sit in geostationary orbit above the Earth, beaming signals for television, Internet and communications to broadcast, telecommunications, corporate and government customers (Telesat, 2012b). None of this would be possible without the sun's power. It fuels the solar arrays that power those satellites, keeping those users happy and Telesat in business.

The sun is a volatile source of energy, and with its great power also – to paraphrase the 2002 *Spider-Man* film – comes great consequences. Those in Ottawa on Jan. 20, 1994 did not feel its power directly; temperatures were a typical minus 24 degrees Celsius in the morning, rising to a high of minus 13 by midday (Environment Canada, 2012). However, those controlling the Telesat satellites were reminded about how fragile machinery can be. Particles streaming from the sun hit Aniks E1 and E2, temporarily wiping out broadcasts. When Anik E2 couldn't be recovered immediately, the crisis pushed Telesat – about to celebrate its 25th year of operations – to the brink of bankruptcy. What's more extraordinary is that the worst didn't happen. A dedicated group of engineers worked to implement a fix for Anik E2 that not only worked, but kept the satellite functioning well for another nine years. It took until June for the crisis to be fully resolved, but their dedication saved the satellite and the company.

Until this thesis, the Anik E2 incident had not been studied extensively outside of media reports and technical papers. The following pages will trace not only the incident itself, but also the history of Telesat and why this incident mattered in the context of the company. The aim is to provide a comprehensive overview of the satellite disruption, its effect on Telesat and the effect on its customers. Should a similar incident happen again, it is this author's hope that the research will assist in making decisions to preserve satellite functionality, customer satisfaction and company finances.

Methodology

Research for this thesis consisted of a combination of documentary research and original interviews with participants in the Anik E2 incident. Seven people were interviewed for the thesis. Five had direct knowledge of Telesat and its operations (either as employees or as observers) and the other two were customers of Telesat. Prior to performing these interviews, permission was sought from the Institutional Review Board at the University of North Dakota. The requirements stipulated signed consent forms for all the interviews, and that an electronic copy of each interview be placed in the Chester Fritz Library. They are available under the University Archives collection (UA#100) for the Center of Aerospace Sciences under this author's (Elizabeth Howell) name. The following is a list of the participants, and their positions and employers at the time:

- Barry Turner (Telesat), director of media relations and an engineer;
- David Boteler (Natural Resources Canada), space weather forecaster;
- Bruce Burlton (Telesat), manager of satellite relations and an engineer;
- John C.P. King (Globe and Mail), deputy managing editor;
- Martin Marcotte (Canadian Broadcasting Corporation), regional engineer for CBC Manitoba. CBC and Radio-Canada;
- Bob Meldrum (Telesat), computer engineer;
- Nick Martens (Telesat), satellite engineer.

The conversations are of subject to a few limitations. The memory of the participants may have been clouded by nearly 20 years of distance between today and the crisis that befell Anik E2. Their recollections are subject to the usual human limitations of giving the truth as one person remembers it, and telling the story of an incident that could be clouded by a person's perceptions. That said, their contributions were invaluable.

The author also performed documentary research into the incident and the history of Telesat. Ottawa's Library and Archives Canada is the official repository of many thousands of government documents. The author found transcripts of the original Parliamentary debates surrounding Telesat’s formation, as well as its subsequent privatization in 1991. Hours of debates were held in the Standing Committee on Broadcasting, Films and Assistance to the Arts in 1968 prior to the signing of the Telesat Canada Act. In addition, Library and Archives Canada held approximately 10 theses of students who examined the history and formation of Telesat in far more detail than what is recounted here. All of these materials were consulted, as they provided a background of the company essential to understanding how Telesat got to where it was today.

The interviews and the documentary materials above formed the bulk of the research for this thesis, but certain other research was also useful in formulating an understanding. Journal articles on topics such as management practices, solar physics and Canadian history were consulted. The author also found Wertz's and Larson's *Space Mission Analysis and Design* a valuable resource in understanding satellite design and mitigation against charging, the effect that brought down Anik E2's momentum wheel. All errors remain the responsibility of the author alone, however.

Statement of the Problem

Telesat had a dual challenge when the Anik E2 satellite was damaged. The first was to rescue the satellite, and the second was to rescue the company since the failure of the satellite put Telesat itself in danger. As stated before, this thesis will trace the timeline of events, and what the company learned to mitigate against future problems.

With regard to Telesat, the crux of the matter was, could this incident have been averted? An argument will be made here that no, it could not have been averted despite the best of intentions. Although the company had recently undergone an ownership change and there had been some rounds of layoffs prior to the Anik E2 event occurring, this thesis will show that solar storms were a phenomenon that were not known as well in 1994 as they are today

There also is a question of whether fixing the problem could have been better managed. It's important to acknowledge that the customers were greatly affected by what happened with Telesat; it took the customers several weeks and great cost to reposition their satellite receivers to get a signal again when Telesat shifted all traffic to Anik E1. Still, Telesat did the best it could under the circumstances. As will be explained later in the thesis, the company informed its customers quickly and had a mitigation strategy in place soon enough for most traffic to continue with little disruption.

In sum, Telesat did the best that it could when confronted with difficult circumstances. The company emerged from the incident more sure of its technical acumen and more prepared for incidents in the future.

CHAPTER II: CANADIAN SPACE PRIOR TO TELESAT

Canada's communications infrastructure in the 1960s posed an expensive challenge for the century-old country. Two things worked against having reliable communications for all of its citizens: the physical size of the country, which is among the largest in the world, and the presence of tens of thousands of people scattered among northern communities that typically are hundreds of kilometres apart. At the time, Canadian carrier companies typically provided communications through landlines as well as microwave relay systems (Chapman & Forsyth & Lapp & Patterson, 1967, p. 18).

This was economical in the southern reaches of the country, where the population density was high. However, the remote north did not have this kind of ready access, limiting the availability of news broadcasts, hockey games and other events. For Canada's national broadcaster, the Canadian Broadcasting Corporation (CBC), recordings of events needed to be shipped to northern broadcasting stations by airplane, which took days at the least and weeks at the most. The shipping and the cost of servicing these stations was "relatively high," according to G.F. Davidson, the president of CBC at the time. (Standing Committee on Broadcasting, Film and Assistance to the Arts, May 8, 1969, pp. 1748-1749). This created a communications divide between northern and southern Canada.

It is important to place Canada in a world context at that time. The government was well aware of the advances in space technology in other countries. The United States and the Union of Soviet Socialist Republics (USSR) engaged in a high-stakes space race through the 1960s that culminated with the Americans landing two men on the moon in 1969. In between the political posturing and the high-profile human space program came advances in communications and weather satellites that allowed for the launches of Telstar and TIROS-1 in the United States, among others. The Canadians were also a minority member of the International Telecommunications Satellite Organization (INTELSAT), which was formed in 1964 to govern international satellite communications. (Johnson, 2002.) Canada had a 3.75% share in INTELSAT and, in the late 1960s, was also on a committee seeking a permanent structure for the organization.

Chapman Report

The Canadian government, aware of these developments, thus appointed a task force to examine Canada's space industry. The goal was to identify the major companies and scientific research entities who were doing work in space and to consider aspirational goals for the Canadian government in regards to the space industry. That effort eventually resulted in a report that became known as Upper Atmosphere and Space Programs in Canada: Special Study No. 1, 1967, more colloquially known as the Chapman Report.

Leading the report was prominent space researcher John Chapman, whose contributions to Canadian space institutions cannot be overstated. He was born in 1921 and at age 28, became a scientist at the Defence Research Telecommunications Establishment in Ottawa. He was the designer and principal investigator for Alouette, Canada's first space satellite. Alouette did research on the nature of the ionosphere, which was then used to bounce radio signals across long distances. The satellite launched in 1962 and remained in operation until 1971. Chapman subsequently became assistant deputy minister for research in 1968. (Franklin, 2012). With this resume, Chapman was likely the most-qualified Canadian to undertake such a study. What he and his committee produced still has much relevance today.

The committee was appointed in May 1966 and held hearings in most major Canadian cities between June and October that year. It received 112 briefs and other communications, and put out requests for information to government departments, industrial groups, universities and technical associations. The subsequent document, the committee said, came principally from the responses to these requests for information. (Chapman, 1967, p. vii).

The resulting paper provided a broad overview of the Canadian space industry, including mention of specific university and industry programs, and gave numerous recommendations. It is considered a foundational document for Canadian space policy, and is also where the push for a domestic satellite program first entered into government discourse. Telesat Canada would come to be as a result of this desire to see domestic satellite communications. Chapman, et al, outlined four main benefits for a satellite built by Canadians and orbiting with a sightline to Canadian soil:

1) Communication with remote communities, particularly in the north.

2) Providing real-time radio programs to northern receiving stations, removing the reliance on tapes that had to be transported physically.

3) Providing long-distance telecommunications traffic. The committee noted this was probably most economically feasible (over terrestrial radio relay) in situations where communities were separated by 1,500 miles or more.

4) Providing direct broadcast to homes or schools, especially in isolated or rural communities. (Chapman, p. 17).

While Canada was participating in international satellite communications through INTELSAT, the Chapman Report made the case that a domestic satellite system was necessary "[b]ecause of the present unsettled state of US (sic) policy on domestic satellite communications." (*Ibid*, p. 19). The United States had created a unique entity, the Communications Satellite Corp. (COMSAT), in 1963 to manage satellite communications. The United States government had oversight of the system and allowed its stock to be divided between communications carriers (50%, with AT&T limited to 29%) and private investors (50%). (Johnson, 2002).

COMSAT had in turn created INTELSAT in 1964. (Johnson, 2002), and was its manager until 1979. COMSAT held a 56% quota of INTELSAT. This concerned the Canadians because COMSAT managed the committee, sat as a representative of the committee, and was also a U.S. carrier – the latter making it subject to regulation by the Federal Communications Commission. It was hard, the Chapman Report stated, for the Americans to separate those roles, leading to conflicts of interest. (Chapman, p. 17). Given that the Americans would want to serve their own interests first, it made more sense for the Canadians to pursue satellite communications independently despite the cost: "It will be difficult for the US and Canada to reach an agreement on questions relating to the purchase, leasing and launching of satellites to serve domestic Canadian purposes." (*Ibid*, p. 19). This argument was enough for the Canadian government to commission a whitepaper to examine domestic satellite communications in more detail.

Run-Up To Telesat Canada Act

At least one scholar believes that the push to develop Telesat was very much due to the way in which the problem of forming a domestic satellite system was stated. The University of Toronto Ph.D. dissertation of Vera Pavri-Garcia argued that interest groups and the language used to describe the problem facing Telesat – specifically, to create a domestic satellite system – made it difficult for other sides to have their say.

> Historically, Canadian policy makers have placed great emphasis on developing advanced communications systems as a way of linking the country's relatively sparse and widely spread out population. Given this preoccupation with communications, it is thus not surprising that Canada was the first country to develop its own domestic system. (Pavri-Garcia, 2005, p. 3)

Debra Slaco, in her 1981 Simon Fraser University master's thesis, discussed the Trans-Canada Telephone System (TCTS) in relation to Telesat. TCTS initially leased capacity from Telesat and had part ownership; later, Telesat became a member of TCTS, giving the entity control over items such as placement of ground stations (see Chapter IV for more on this topic). Slaco pointed out that TCTS had two main functions: first, to establish the parameters (including planning, construction and standards) for a national network in conjunction with United States planners.; and second, to serve as a forum for members to provide and share market research and technological details. While the entity itself does not own any hardware, member companies do. Members of the TCTS also divided administrative and service expenses among themselves while sharing in the profits of their joined system. Among these companies, Bell had the greatest influence on Canadian policy due to its prominence in Canada. Slaco pointed out that there is no regulatory oversight of TCTS, since it is not a company. (Slaco, 1981, pp. 51-52).

Federal Industry Minister C.M. Drury led a task force examining the domestic satellite possibility in more detail, and in the first pages of the white paper came out unequivocally in support of such a system: “In brief it is the Government's conclusion that a domestic satellite communication system is of vital importance for the growth, prosperity, and unity of Canada.” (Drury, 1968, p. 8.) The paper stated it would take a very large expansion in microwave relay systems to obtain the increase in capacity that the government wanted. Canada, the report noted, is a country of large distances. A satellite would be the best way to reach the entire country. (*Ibid*, pp. 32-36 *passim*).

In 1991, thesis student Wendy Marston, quoting a 1969 book by Charles Dalfen, a former commissioner of the Canadian Radio-television Telecommunications Commission, noted that no cost-benefit analysis was performed comparing satellites and microwave (Marston, 1991, pp. 185-86.) There are two possibilities why this wasn't considered, of course – the first could be that persuasive talk swayed the audience. The second was, perhaps, that it was clearly obvious to policymakers that satellites would be cheaper.

There was enough industrial capacity for satellite manufacturing in Canada, the report noted. At least three separate proposals were made by Canadian company consortia seeking to build systems of their own.[1] These firms already had established track records in satellite communications. For example, RCA Victor did systems integration, management, sub-system design and manufacturing for a communications satellite earth station at Mill Village, Nova Scotia. The station was finished in 1966 and used for INTELSAT's first satellite, Early Bird. The station cost $11.5 million. (Chapman, p. 42).

One other impetus spurred the Canadian government to act immediately. It was concerned that other countries' efforts to build and launch communications satellites would squeeze Canada out of geostationary satellite “slots” at the equator that had a sightline to Canada. Those spots were allocated on a first-come, first-serve basis and only a certain number of satellites could be placed there without interfering with each others' operations. “The development of communication satellites is proceeding rapidly in Europe and the United States, and these will soon be laying down signals over parts of southern and eastern Canada,” the report warned. (Drury, p. 36). The possibility was enough for the new Pierre Elliot Trudeau government to get moving on an act that would see a domestic satellite company form, under the umbrella of the government.

1 In March 1967, Trans-Canada Telephone System (a consortium representing a majority of Canadian telephone lines) and Canadian National/Canadian Pacific Telecommunications proposed a satellite communications system before government. RCA Victor Co. Ltd. had a proposal with definitive design criteria in September 1967. And in January 1968, Northern Electric Co. - the predecessor to Nortel – signed an agreement with Canadair Ltd. and Hughes Aircraft to design and build equipment for satellite communications. (Drury, p. 38).

CHAPTER III: FORMATION OF TELESAT

In early 1969, the Trudeau government proposed the Telesat Act to form a corporation, with government participation, that would launch Canada's first domestic communications satellite. According to newly appointed Minister of Industry Eric Kierans, a Liberal party member noted for his economic nationalism, the new satellite would provide television coverage and communications services to the North and "underdeveloped regions", offer television service "in both languages to all Canadians", and act as a supplementary service to Canada's existing west-east microwave network. The total cost was expected to be $65 million to $75 million, which included $40 million for the satellite, $6 million for the launchers, and $20 million for the ground station. (Kierans, 1969, p. 7493).

The government, he added, rejected the notion of fully privatizing Telesat or, by contrast, making it fully public. Private ownership would leave Telesat out of government hands except in the case of legislating certain activities. Public ownership, Kierans said, would be overly and unnecessarily costly to the taxpayer.

> Outer space, carrying with it major considerations of international policy, should not, in the government's judgment, become the preserve of a privately-owned corporation. The other alternative, at the other end of the spectrum, is a wholly government-owned enterprise. The government could, at the taxpayers' expense, build and operate the system by itself. We have rejected this

> alternative. The reason is that the common carriers have acquired an outstanding expertise in the economic development of telecommunications. (*Ibid*, p. 7495).

Members of the opposition had several concerns with the proposal. The New Democratic Party's Edward Schreyer wondered if this "hybrid" ownership, with 30% government ownership and 70% private, would make it difficult to distinguish whether the company itself was public or private. He suggested the company be instead made a Crown corporation (Schreyer, 1969), which under Canadian law is a fully owned provincial or federal entity that acts like a private corporation. (Tupper, 2012). This position was supported by fellow party member John Gilbert (p. 7527) and Conservative Heath MacQuarrie (pp. 7051-2). However, a motion to make Telesat a Crown corporation was defeated in the House of Commons (Edited Hansard, 1969, p. 7536).

Committee Debates

On April 22, Minister Kierans appeared at the first hearing of the Standing Committee on Broadcasting, Films and Assistance to the Arts. Perhaps still sensitive to the Commons debate surrounding the Crown corporation, his opening remarks specifically addressed the issue by saying that kind of structure for Telesat would be the easy way out. "It would rid me of a lot of headaches. Drafting legislation for a Crown corporation would be relatively simple .... (and) I would have no more worries about cost and efficiency." (Kierans, Standing Committee, p. 1475).

However, he said government ownership was “the easy way out” for Telesat ownership due to what he characterized as less emphasis in government on spending money wisely than in the private industry.

> We have rejected the approach attempted in the United States where COMSAT is owned jointly by the public and the carriers with minority government membership on the board of directors. In the instance of the domestic satellite corporation, government membership on the board will be backed by direct government share ownership. Continued government involvement is assured in several sections of the bill dealing with such matters as Canadian content of the hardware. (*Ibid*, p. 1476.)

When further pressed by committee members, he said the initial government stake would be $20 to $30 million and that cost savings had already been achieved. The government reduced the number of proposed satellites in orbit (from 2 to 1), which saved $11 million, and the number of satellite channels (from 11 to 6.) *(Ibid*, pp. 1486-1502 *passim*.) Kierans added it would cost $65 million to do it entirely out of the public purse. “Sure we can go it alone, but we can do a hell of a lot better job if (private partners) are there.” (*Ibid*, p. 1514).

The argument was met with skepticism from Ralph Stewart, a fellow Liberal on the committee. He pointed out that the initial government whitepaper on building the satellite system was well done, but had its goal of selling the idea of a satellite rather than critically examining its use. As such, he urged the committee to seek as many outside opinions as possible to make sure that Telesat would be a worthy investment.

> [I]n my view there are some serious questions as to the economic feasibility of this project at a time when we are preaching hold-the-line budgets and austerity measures. I

> am not against a satellite system. I shall be overjoyed if we are able to have one in the near future, but I insist that it is necessary for us in this Committee to get opinions other than those who have an axe to grind or other than those who are involved in the government project to establish such a corporation. (pp. 1583-84)

Despite his skepticism, the system did meet with approval from the participants that mattered most. The chair of the Trans-Canada Telephone System, J. H. Krupski, said the satellite would be "a desirable addition to the Canadian telecommunications network." (Krupski, p. 1678.) His only concern was that he believed that the Act should specifically prohibit competitive carriers from renting out channels on the satellite (pp. 1679-80); this was addressed by the final, published version. As evidence of the importance the carriers placed on this system, at least one of these carriers, Bell Canada, said private industry was prepared to go it alone with the other members of Trans-Canada if the government did not step up to fund it. However, Bell cautioned it could not speak on behalf of all the carriers (Lester, p. 1849.)

The head of the Canadian Broadcasting Corp., G.F. Davidson, pointedly asked if his Crown corporation would receive the necessary federal funds to participate in the satellite. He noted that if a satellite did go forward, the funds allocated to shipping tapes up north would instead be shifted to renting out a satellite channel. "As of this moment the Corporation has no means of knowing whether it will be given the public funds to extend the French and Northern Services either by satellite or by microwave and tape. This is a matter for Parliamentary decision." (Davidson, pp. 1748-50).

Marston pointed out that broadcasting interests were not specifically included in

Telesat's ownership structure, an interesting point because satellites are useful both in broadcast and network services. However, the carriers already had point-to-point communications services in the south, leaving the north as the only spot where Telesat could dream of being competitive. Also, the carriers threatened to leave the Telesat agreement unless the broadcasters, namely CBC, were restricted to leasing channels only.

> The fact that broadcasting interests were not represented in Telesat's ownership structure says much about the power that the common carriers wielded with the government at the time – power that was based on the carriers' ability to financially support Telesat in its early years. The carriers played an all-or-nothing game in their negotiations with the government, and ensured their control by restricting Telesat's leasing capabilities. This did much to ensure that Telesat would not pose a competitive threat to the common carriers during its first decade of operations. (Marston, p. 100).

What's interesting is how that situation persisted long after the carriers and the railroads saw their influence decline in Canada. At the time Anik E2 malfunctioned, broadcasters were still leasing services from Telesat. Today, the same situation occurs; for example, Bell has a 100-per-cent lease on Nimiq 6's channels to provide direct-to-home services. (Telesat, 2009). Given declining advertising revenues for broadcasters, it is unlikely they would be interested in purchasing physical assets, especially considering satellites have a typical lifetime of maybe 10 or 15 years. Still, the carriers did effectively lock broadcasters out of having ownership in the early days of Telesat. This meant the company did not have to answer to the broadcasters in any way save as customers.

With the amendment concerning carrier participation back in hand, the bill went back to Parliament. As Conservative Stanley Schumacher noted, “this bill does not have the unanimous support of all members" – which is true of most bills before Parliament. (Schumacher, 1969, p. 10100). New Democratic Party MP David Lewis, a past member of the same Standing Committee that examined Telesat's structure (Parliament of Canada, n.d.), said he worried that too much of Telesat's interests lay in private hands:

> It is impossible for me to see how the minister can avoid the simple fact that that arrangement would place this company, essential to Canada's political and social development ... in the control of the private corporations of the country, those corporations that already have too much control in the field of communications. (Lewis, 1969, p. 10101)

Nevertheless, only 11 Members of Parliament voted against the Telesat Act. (Edited Hansard, 1969, p. 10118). The act was assented to on June 26, 1969 and became effective on Sept. 1, 1969. (Bush & Rigley & Jha, 2003). Parliament's control of Telesat would last for about a generation.

Main Features of Telesat Canada Act

It should be noted that the only copy the author could find of the Telesat Canada Act in Library and Archives Canada was a supplement to the original version tabled in 1969. However, the supplement was tabled in 1971, only two years hence. The version read for this thesis delineated the structure of the company as well as its main responsibilities. (Telesat Canada Act, 1971.) The objective was to establish a commercial telecommunications system for Canada. Telesat was ordered to use, to the most practical extent, Canadian technology in regards to "research, design and industrial personnel (and) technology and facilities in research and development connected with the satellite telecommunication systems and in the design and construction of the systems." (*Ibid.*) Its powers included designing, constructing, operating and maintaining satellite communications systems, conducting research and development into satellite communications, and "making arrangements" to launch the system. It is interesting that a country so worried about controlling its satellite system did not make provision for an independent launch capability, which is a situation that persists in Canada to this day.

The act invoked another piece of legislation, called the National Capital Act, which guaranteed Telesat would be located in the capital. This was in accordance with Section 24 of the Canada Corporations Act, with that latter act stipulating that all Canadian head offices must be located in Canada. (Canada Corporations Act, 1970.) A reading of the National Capital Act shows that it was intended to develop and improve the Ottawa region (National Capital Act, 1985). This implies the government saw such importance in Telesat that it insisted on locating it in Ottawa – close to Parliament.

While specifically stating it was not a Crown corporation, the act stated Telesat did need to ask the permission of the Minister of Industry to perform certain actions. This included satellite construction, and taking holds or shares or debentures or securities of another company. Other government departments or agencies looking to enter into contracts with Telesat needed to ask permission of the Treasury Board, which is a cabinet-level committee consisting of the Minister of Finance and four other ministers. (Hodgetts, 2012.) The Minister of Finance also had the power to subscribe for, acquire and hold common shares and also to transfer them or dispose them on behalf of the government. That latter power was subject to approval of the Governor in Council, which is Canada's Governor General (head of state) acting with advice from the Parliamentary cabinet. (Forsey, 2012). In other words, given these restrictions, Telesat needed to go through government approvals before conducting much of its business.

Even though the government held a minority share of the company, its agents held considerable power over the future of the Canadian domestic satellite communications system. That said, there were provisions to give companies and private citizens a measure of control as well. Telesat Canada's board would consist of seven people who were not in the public service (e.g. not government officials) and also were not officers or directors of a telecommunications carrier with interests in Telesat. Board duties included setting times of meetings, allotting and paying shares, declaring and paying dividends, paying directors and managing and administering company property.

Shareholders, of course, had their powers as well. Notably, it took two-thirds of shareholders to vote in certain provisions; since the government itself had a 30% share, it was theoretically possible for the carriers and private citizens who held the other 70% to overrule certain provisions, although there was no record found of this occurring. Shareholder powers included extending company objects beyond broadcasting, changing the objects or powers of the company, reducing the number of authorized shares or cancelling them, and altering the authorized capital of the company.

With the company now formed, it was time to turn to the problem of how to get a domestic satellite system established. That would be Telesat's next preoccupation.

CHAPTER IV: TELESAT HISTORY OVERVIEW

As stated before, Telesat was initially owned by both the federal government and Canadian carriers. This changed slightly when in 1975, the Trans-Canada Telephone Systems (TCTS) approached Telesat to become a member. The next year, the Canadian cabinet approved an interim agreement that stipulated the federal government would still have exclusivity over satellite communications, and that Telesat could do consulting work – but was still not allowed to own or operate ground facilities. (Marston, p. 132). The Canadian Radio-television Telecommunications Corporation was not in agreement with the decision, saying that the emphasis of TCTS of providing service to its members would shut out the interests of broadcasters, namely the CBC whose very mandate called upon it to provide services to the north. The government overturned the CRTC's concerns, and the legislation passed. (Marston, p. 143).

As far as the author could tell, Telesat was a member of TCTS when Anik E2 launched in April 1991. It should be noted that Telesat is still a member of TCTS today, although the consortium has undergone some changes and it is now known as Stentor. Today it is an association of nine telephone companies and Telesat. (Babe, 2012).

Prior to the satellite's launch, however, the federal government announced it would sell its 53% interest in Telesat as part of an ongoing move to privatize Canadian Crown corporations. As of February 1991, the federal Conservatives had sold 20 of these corporations, since taking office in 1984, in an effort to reduce expenses. (The Financial Post, 1991). As a side note, it's interesting to note Telesat was formed under a Liberal government and privatized under a Conservative, but analyzing political bents is beyond the scope of this thesis.

In 1992, the $154.8 million sale of Telesat was approved for buyer Alouette Telecommunications Inc. This was a consortium of several companies that included Bell Canada Enterprises (BCE) and Spar Aerospace Ltd. (Lacasse, 1992.) BCE subsequently bought out its partners in 1998. (Jane's, 2011). As will be explained later in this thesis, the current owners are Loral Space & Communications and Canada's Public Sector Pension Board, which both bought Telesat from BCE.

Privatization Debates in Parliament

The government of the day, which was Brian Mulroney's Conservatives, did not consider selling its interest in Telesat shares to be privatization. As the company was not a Crown corporation to begin with, argued Minister of State John McDermid, selling the government interest was not technically privatizing the firm. (McDermid, 1991, p. 5005.)

This is an interesting stance for the government to take given that the Telesat Act outlined restrictions such as who could own shares in the company, who could sit on the board of directors and what business Telesat could engage in – notably, consulting services were not specifically included, which is a business line that the company engages in today. (Telesat Canada, 2012d). The company may not have been a “public” company by McDermid's and the Conservatives' standards, but there certainly were public restrictions on Telesat's operations that would be removed once the government sold its shares.

Telesat was set up with an initial plan to give the government a 30% interest, the carriers a 30% interest and the public at large a 40% interest. For reasons that McDermid did not specify, the public never received an invitation to buy shares. As a consequence, some of that responsibility was taken on by the government. At the time of the debate in Parliament, some 53% of Telesat shares – more than half the company – were held by government entities. The federal government owned 49.3% of shares and Canadian National Railways, a Crown corporation (Tucker, 2012), held 3.7%.

While not providing a detailed rundown of Telesat's finances, McDermid added that the company owed the government $30 million from a loan. (McDermid, p. 5006). Moments later, he called the company a "commercial success story" that had no need of government intervention, which was interesting given the amount of money owing the government. As an aside, the next day, a Liberal – Mac Harb – said Telesat had net earnings of $23 million in 1989 and $30.5 million in 1990. (Harb, 1991, p. 5103).[2] McDermid pointed out Telesat owned and operated six satellites, as well as overall commercial satellite services and facilities around the globe. Revenues come from leasing satellite capacity to broadcasters and firms, and some consulting.

> In other words, Telesat Canada is a commercial success story and no longer requires government participation to

2 The author attempted to find records of Telesat's financials during this period of time, but determined the work required was outside of the scope of this thesis. Government records are sparse on the Internet before about 1995 or 1996, and Telesat itself said it does not have records due to the many ownership changes over the years. Copies of the federal 1991 budget are stored off-site at Library and Archives and could not be obtained in time for the thesis proposal date.

> fulfill its public policy role. In fact, continued government participation does not represent an appropriate use of taxpayers' dollars. Moreover, selling the government's Telesat shares will give the company both a stronger incentive and a more flexible means of pursuing its commercial opportunities. (*Ibid,* p. 5006)

He pledged that for the next decade, the government would not grant licenses to any other telecommunications carrier seeking to provide similar satellite services in Canada. McDermid stressed this was important both to let Telesat grow on its own, and also to allow it to provide services to the north, where it was the "primary vehicle" for people in those communities to receive information by satellite. (*Ibid*, p. 5007).

The parties that had so eloquently expressed skepticism that Telesat could achieve commercial success when it was founded now came out in favour of the company's work. They also worried that the government was abandoning the enterprise too soon, before it was fully ready to stand on its own two feet.

Derek Lee, a Liberal and long-time Telesat supporter in Scarborough-Red Rouge who is still serving in Parliament as of the time of this thesis writing, said Telesat had done "extremely well" given it had doubled its revenues in the past five years. Still, he asked that the government consider the need to keep Telesat strong not only nationally, but internationally. (Lee, 1991, pp. 5009-5010).

> (W)e know we are entering a domain of global competition. We are just at a time when Canada's industrial sector including the telecommunications sector needs all the help it can get. We need all the government support we can muster to challenge the world. Just at that point in time the government has chosen to bail out of Telesat. I do not know whether the timing is good. I suggest that it may not be. (*Ibid*, p. 5010).

The New Democratic Party's Lyle Dean MacWilliam, with considerable prescience, worried about the company's future once its satellites that were currently in orbit reached the end of their useful life. Telesat, he said, had a high debt-to-capital ratio and was likely to lose money unless it raised its rates. (MacWilliam, 1991, pp. 5014-5015). It is worth noting again here that the failure of Anik E2, a single satellite, brought Telesat to its knees. Apparently the company was therefore financially vulnerable at the time that the debate was taking place.

Members of Parliament also expressed concern about Telesat's financial viability after privatization, citing other companies that had experienced problems after the government sold its interest. Examples cited included how national train service VIA Rail sharply curtailed its service after privatization (Callbeck, 1991, p. 5039), and the threat of lost jobs at de Havilland, which had also lost government financial support recently (Mills, 1991, p. 5048).

The bill to divest the government's Telesat stock was referred to a legislative committee. (Edited Hansard, 1991, p. 5113). There would be one final significant parting shot in Parliament concerning Telesat that December: George Baker, a Liberal, noted there was a $300-million debt when the Anik E2 satellite did not work upon launch, a situation that will be discussed in a later chapter. He said a previous order in council ordered the Canadian Radio-television Telecommunications Commission, which regulates broadcasting in Canada, “to take into account the risky business of putting up satellites (and) the incredible cost, involved ... to re-examine the cost structure of Telesat and to put it on a firm financial footing because of these debts and the ups and downs in the satellite business." (Baker, 1991, p. 6160).

It is said that hindsight is 20-20, but it is interesting to look at Baker's remarks while thinking about what happened next to Telesat regarding that same satellite. Nevertheless, the bill to divest the shares passed (Edited Hansard, 1991, p. 6165) and received royal assent on December 17, 1991 (*Ibid*, p. 6244). It was now time for the BCE era of Telesat to begin.

BCE Acquisition and Subsequent Sale to Loral, PSP

The Telesat takeover was one of a large set that BCE was pursuing in the late 1990s, and the rapid pace of acquisition ended up costing BCE dearly. By 2008, BCE was labouring under US$33 billion in debt before becoming privatized. (Tedesco, 2008.) Prior to privatization, the company had attempted to raise cash through selling some of its acquisitions. Among those was Telesat; on December 1, 2006, the United States' Loral Space & Communications Ltd. and Canada's Public Sector Pension Investment Board announced they would form a joint venture company to purchase all of Telesat's shares from BCE for US$2.8 billion or what was then CDN$3.25 billion. They also agreed to take on US$148 million (CDN$172 million) in debt. (Loral, 2006).

The deal came under scrutiny in both Canada and the United States as the transaction led to a majority Canadian voting interest of 66.6%, but a majority United

States economic interest of 64.3% (Federal Communications Commission, 2007). Several investment funds in the United States alleged that Loral's decision to sell $300 million in stock to finance the takeover was “unfair” and did not serve minor shareholders, a petition that was later overturned. (Montreal Gazette, 2007). In Canada, approvals took a year as the Competition Bureau examined its “net benefit” to the country. Considerations the Bureau takes into consideration include making sure customers have adequate choices between competing vendors – in other words, avoiding a monopoly – and ensuring that the transaction serves the affected parties, the public interest and the private interest. (Competition Bureau, 2011.) Approval became official in October 2007. (BCE, 2007).

2010 Review of Telesat's Future

This section serves to close the circle in the ongoing number of ownership changes Telesat underwent in its history for those readers who are interested in where Telesat stands today.

In recent quarters, Telesat representatives have repeatedly stated its profits have been affected by fluctuating currency exchange rates, particularly since much of its business comes from the United States. (Howell, 2010.) The Canadian government announced in 2010 it would loosen foreign government restrictions on Canadian firms to encourage venture investment (Government of Canada, 2010), a move chief executive Dan Goldberg advocated in remarks to the federal government's Standing Committee on

3 Technically speaking, the Public Sector Pension Investment Board purchased Telesat through a series of holding and temporary company transactions and it is one of those subsidiary holding companies that owns the board's interest in Telesat.

Industry, Science and Technology in May 2010.

> Notwithstanding the fact that we're one of the largest operators in the world and enjoying a good measure of success of late, we have no illusions about our position in the broader industry. Put plainly, Telesat remains dramatically sub-scale relative to our three much larger competitors, all of whom have been authorized by Industry Canada to serve Canada and none of whom are subject to foreign ownership restraints by their principal regulators. (Goldberg, 2010.)

In November 2010, Telesat announced its board of directors “authorized management to explore an initial public offering of Telesat’s shares or other strategic alternatives that may arise.” (Telesat Canada, 4 November 2010). On Aug. 4, 2011, the company announced it had received and rejected takeover offers from several parties, indicating the ownership structure would not change for the foreseeable future. (Telesat Canada, 4 August 2011). The firm subsequently examined other options for its owners, “including potential recapitalization transactions for the primary purpose of paying a dividend or otherwise returning capital to shareholders,” but abandoned that plan in November 2011 (Telesat Canada, 4 November 2011) due to fluctuating market conditions and tax and structural considerations (Howell, 4 November 2011).

Just one quarter later, Telesat's board of directors and shareholders changed their minds. In February, the company announced it would refinance existing senior secured credit facilities and use cash on hand to pay the company's owners up to CDN $705 million. (Telesat Canada, 22 February 2012). On March 28, the company announced it would take out several credit lines in the amount of CDN $2.55 billion. About $2.1 billion would service a credit line that had expired. The remaining $400 million would be combined with cash on hand to pay Telesat's owners and certain employees, for the previously stated amount of $705 million. (Telesat Canada, 28 March 2012). When asked by analysts why the refinancing was being pursued, Goldberg said it was because market conditions had improved and that more revenues were expected to flow from the launches of Nimiq 6 and Anik G1 later in 2012. (Howell, 22 February 2012).

In a conference call in early May, an analyst asked Goldberg if given the dividend, it was possible the firm could be put up for sale sometime soon. Goldberg said he did not see the two as connected, added the company was still focused on putting the two new satellites in orbit. He remained vague as to whether the firm could review its ownership again. (Howell, 27 April 2012.)

Still, it is this author's view that Telesat is attempting to position itself for a sale. The company is engaging in a few high-profile projects at the moment. The refinancing is one of them. In addition, in early 2012 it proposed a $160 million public-private partnership to upgrade satellite broadband in the north. Negotiations are ongoing. (Telesat Canada, 2 February 2012). The company is also diversifying its satellite base to maintain strong revenues. Although it posted a 3% reduction in revenues in the first quarter of 2012, the latest results available, the firm noted that this was due to a contractual change in one (unnamed) direct-to-home satellite operation. This was partially offset by growth in the international satellite business as well as cash flow gained from the Canadian payload that Telesat operates on ViaSat-1. (Telesat, 27 April 2012). The company's small size is something that Goldberg has pegged as a hindrance against what Telesat considers its much larger competitors: SES, Intelsat and Eutelsat. (Telesat Canada, 2012c).

CHAPTER V: ANIK E2 LAUNCH AND SOLAR STORM

When the $300 million Anik E2 lifted off from French Guiana on April 3, 1991, a group of Telesat and Spar engineers gathered at the Ottawa Congress Centre to watch the live feed from television. After cheers and whoops from the onlookers, spokesperson Darrin Shewchuk took a few moments to speak to a reporter on the scene. “We're out of intensive care and on the stable list now,” he proclaimed, adding an unwitting statement of prescience: "We're out of the critical stage where there's the most chances of something going wrong, but we'll still have some nervous technicians and engineers for another week and a half.” (May, 1991).

Anik E1/E2 Technical Features

One NASA scientist called Anik E2 and its twin, Anik E1, “the most powerful satellites in commercial use in all of North America.” (Odenwald, 2000). They were intended to replace the older satellites in the successful Anik line, most critically Anik D1, which was nearing the end of its fuel and could not maintain its orbit to reliably transmit signals to fixed ground station antennas. (Flavelle, 1991).

For a generation, Anik was a staple of Telesat's roster of satellite types. The pioneer that was launched in 1972, Anik A, was the first domestic synchronous communications satellite worldwide. Its shaped beam – a global first (Boeing, 2012) –

provided communications for Canada's north, specifically Frobisher Bay and Inuvik, as well as most southern regions of the country. (National Museum of Science and Technology, n.d.) This allowed the Canadian Broadcasting Corporation, the country's national broadcaster, to send its signals north for the very first time. (Canadian Broadcasting Corporation, 5 February 2007). With 12 C-band transponders on board providing colour television transmission capabilities, the satellite proved so successful that Telesat launched sister satellites Anik A2 and Anik A3 in quick succession, in 1973 and 1975. (Telesat Canada, 2012e).

By the time Anik E2 launched in 1991, satellite technology had improved considerably and Telesat had honed its expertise through the Anik B, C and D lines. The 2,390 kg satellite boasted 24 C-band and 16 Ku-band channels. *(Ibid*). Its transponders were three times as powerful as the Anik C satellite series launched a decade before. (Bush & Rigley & Jha, 2003). Engineers from both Spar Aerospace (now a division of MacDonald, Dettwiler and Associates) and GE Astro designed and built the satellite, while Telesat served as the operator. In a book produced by Spar Aerospace, the author referred to the Anik E line as “the largest, most powerful dual-frequency satellites to be placed in commercial service over North America.” (Dotto, 1992, p. 111).

Anik E2 Antenna Issues and Resolution

Naturally, that statement was contingent on the satellites actually working – a fact that troubled Anik E2 from the beginning. The satellite reached geosynchronous transfer orbit easily and also performed well in a series of apogee burns to put it in the right orbit.

But on April 6, 1991, Telesat attempted to deploy Anik's Ku-band reflector and could not confirm, through readings from Anik's gyros, that it had succeeded. (Wang & Martens, 1993, pp. 812-13). Engineers also commanded the C-band reflector to deploy through firing four “tie-downs” bolted to struts on the satellite. *(Ibid*, p. 811*)*. That command failed to execute as well. (*Ibid*, p. 813). Engineers reversed the spin on the satellite and managed to deploy the Ku-band antenna by April 15, but the C-band remained undeployed. (Dotto, pp. 112-13).

After running through several fault analysis scenarios in subsequent weeks, engineers narrowed down the cause to the thermal blanket covering the C-band to protect it from solar radiation. The top of each “tie-down” on the reflector sat on top of a blanket, which was attached to the reflector with Velcro strips and reinforced with Kapton tape. Testing in Ottawa's David Florida Laboratory determined that under the worst conditions, the blanket could pop out and interfere with the straps. (Wang & Martens, pp. 813-14).

Further testing showed the antenna would dislodge with a minimum of 1.2 pounds of force, which engineers could achieve if the satellite was spun at four revolutions a minute, 20 times faster than what the initial design called for. After making some orbital changes to lessen the burden on a hinge carrying the satellite's power and electronics box, engineers executed the maneuver successfully on July 2. Subsequently, Anik E1 was launched with changes to its tie-downs in October, and deployed all antennas without incident. (*Ibid*, pp. 814-15).

The Solar Storm

Carrying most of Canada's broadcast signals, Anik E1 and E2 subsequently did their work virtually flawlessly for more than two years, until the afternoon of Jan. 20, 1994. Astronomers monitoring the sun that morning had seen no unusual solar activity, recalled NASA astronomer Sten Odenwald. “There were no obvious solar flares in progress, and no evidence for any larger-than-normal amounts of X-rays, but a series of coronal holes had just swept across the Sun between January 13-19th,” he wrote. (Odenwald, 2000).

A few signs of trouble began to emerge. The NOAA Space Environment Center tracked high-speed solar wind from “coronal holes,” areas where the sun's plasma is less dense than usual and moves out at higher speeds. Then NASA's SAMPEX satellite began to pick up high-energy electrons in geosynchronous orbit, where the Aniks orbited. Observers using the satellites determined it was coming from changes in the Earth's magnetic field:

> These particles came from the passage of a disturbance from the magnetotail region into the inner magnetic field regions around the Earth. Within minutes, the GOES-4 and GOES-5 weather satellites began to detect accumulating electrostatic charges on their outer surfaces. (*Ibid*.)

In general terms, when plasma hits a satellite, it can artificially create a negative electrical charge. In transistors and semiconductors, this can lead to single-event upsets (SEUs), or temporary “blips” in the way the spacecraft functions. At worst, the charge can create a single-event burnout that damages the way the spacecraft functions. At geosynchronous orbit, where the Aniks were orbiting, surface charging happens during magnetospheric substorms (Tribble *et. al.*, 2010, pp. 213-14) such as the one Odenwald described above.

For users of Anik, the first sign of trouble came at 12:34 p.m. that Thursday. Don Wintzel, the national sales and marketing manager of Novanet Communications, was trying to use Anik E1 to send news from outlets that included the Canadian Press, Reuters and Broadcast News. The disruption stopped the news from flowing and kept it that way until 7:56 p.m., he recalled in a newspaper interview. “It was the largest story in the telecommunications industry in the country and we had no way to transmit it,” he said. (Hanlon, 1994). According to another media report, The Canadian Press could not deliver all of its news to the 100 newspapers and 450 radio stations who were members of the co-operative at the time. (Flavelle, 1994). (Officials from the Canadian Press and Novanet who recalled the incident declined interviews for this thesis.)

Natural Resources Canada was also picking up indications of unusual solar activity. One of the responsibilities of this government department is to provide space weather forecasting; David Boteler was a research scientist there at the time. In an interview for this thesis, he said that as with other users, the department was simply reacting to what it saw. However, the advantage was they had instruments giving them information on what was happening and could pass that information along to Telesat.

> We were seeing elevated levels of energetic electrons at the geostationary orbit. There’s [*sic*] instruments on the GOES satellite operated by NOAA that was measuring our [*sic*] energetic electrons, specifically the electrons with energies greater than 2 MeV. We could see elevated levels of the greater than 2 MeV electrons ... It was significant in terms

> of the energetic electrons. In terms of the magnetic activity, it was not so significant. There was ongoing magnetic activity, and that is one of the contributing things that causes the energization of the electrons. But it wasn't [the] dramatic storm that was needed to affect systems on the ground. (Boteler, interview, April 10, 2012).

When the storm hit Anik E1, engineers saw it had knocked out the electronics for the satellite's momentum wheel control electronics apparatus. The 0.39-inch thick gyroscope, which was about the size of a dinner plate, rotated 6,000 times a second. It served as a counterbalance to stop the satellite from spinning and to maintain a constant attitude – and accordingly, stability for signals. Once the wheel stopped spinning, Anik E1 itself began to spin and throw off the antenna alignment. Fortunately for engineers, Anik E1's backup momentum wheel was still working properly and engineers could communicate with the satellite through its omni-directional antenna. It took seven hours to come up with a fix, but when that was achieved, the satellite came back online without a hiccup. (Hanlon, 1994).

Barry Turner, who was vice-president of sales and marketing at Telesat at the time, credits that success to the ability of the emergency committee to convene, evaluate the problem and fix it as fast as possible. The committee was made up of a cross-section of people from all different departments of Telesat, ranging from senior management to people who worked directly on the satellites themselves.

> As it happened on that particular day, most of the executive [senior management] was away so there was only myself, and the chief financial officer in town. Eventually we were able to reach everybody and get them all back in but it was relatively short-staffed at the senior management level. (Turner, interview, 9 May 2012).

Only an hour after Anik E1 recovered, Anik E2 reportedly went down at 9:15 p.m. (Rosenberg, 1994). (Memories of participants in the interviews were not accurate enough to verify the exact time.) Although the impact on users was about the same, the long-term situation was more serious with the latter satellite; both control wheels were malfunctioning. The satellite began rotating once every two minutes – "sitting quietly", in the words of Len Stass, Telesat's vice president of space systems – and remaining uncommunicative with Earth. (Rosenberg, 1994.)

Members of the emergency team that had so quickly convened to solve Anik E1 were going home at that point, recalled Turner. When Anik E2 failed, he attempted to contact the team, but there was a problem. Not only were cell phones uncommon at the time, but the pagers the team used – unbeknownst to anyone then – "looped through the satellite," he recalled. "So the pagers were out too." Turner and others had to use land lines to reach the emergency team members. (Turner, *ibid*.)

> So eventually we were getting the team back. We only had one satellite operating, but now it's full panic station. I'm getting calls from president of the CBC, the minister of communications, generals in the military because the north warning system is out and… I mean it's really, really serious. Now we have no certainty of being able to restore so the impact… we realize very quickly we cannot restore that satellite. (Turner, *ibid*.)

This disruption had an even wider effect as it was in the middle of primetime programming for Canadian viewers in the Eastern time zone, and during the time when some newspapers were sending their pages to the press. At the Canadian Broadcasting Corporation, the company lost both its collection capacity and distribution capacity, recalled Martin Marcotte, then the regional engineer for CBC Manitoba. Collection is defined as when the agency sends information from one CBC production centre to another; television programming mainly used the satellite, while radio used terrestrial circuits. At the time, a Bell Canada company had a service called Video Route that allowed television to be broadcast on terrestrial lines, a service that CBC requested immediately. However, the lack of lines in the north necessitated CBC to reposition its satellite dishes after Telesat moved CBC's traffic to transponders on Anik E1, he said.

> At the production centres, which are in the major cities of Canada, it took less than a day simply because we have technical staff in the location. However on the distribution side – which means point to multi-point, where we're sending programming to northern Canada at that time – we were using satellite technology to send the programming to the transmitters in northern communities at that time, using C-band. They of course lost service … and we had to go to each of those locations to repoint the dishes. We did not have an immediate alternative for the programming. So we had to deploy technical crews to, I think at the time, was around 100 locations. We had all the dishes repointed within five days. (Marcotte, interview, 27 April 2012).

This came at a cost to CBC, of course. When the traffic was then moved back to Anik E2 later in 1994, CBC repositioned all of the dishes to receive the signals from Anik E2 again. However, that was over a period of weeks since it was not critical to immediately move the signals from one satellite to the next. (Marcotte, *ibid.*)

The *Globe and Mail* was sending its sections by satellite to other locations in the country – Moncton, New Brunswick; Montreal, Quebec; Brandon, Manitoba and

Vancouver, British Columbia, when Anik E2 broke down. At the time, the newspaper's custom was to send the sections by satellite to other cities, but to do printing from a negative in Toronto. According to John C.P. King, the managing editor of the Globe at the time, having the negative backups practically saved the day. But there was a problem.

> When we lost that satellite, it caused us big problems because when we needed to print the newspaper in Vancouver and Moncton for instance ... there was no way we could get our newspaper to our readers across the country if we had to print them all in Toronto. And we couldn't print them all in Toronto any longer anyway because we didn't have the capacity to do that. (King, interview, 22 December 2011).

The *Globe*'s (admittedly expensive) solution was to send the negatives out by plane to each of the printing locations. Where possible, the newspaper would send people out using commercial flights, but in a couple of instances the printing plant was not well-enough served by conventional service to do that. In that case, the Globe used a Learjet. Deadlines were not being met, but the papers were still being delivered, said King, at least as far as he recalls. (*Ibid*.)

Much later, when it was determined that the momentum wheel systems had caused the failure, one question preoccupying Telesat was why one of the four wheels on the two spacecraft did not fail. Bruce Burlton, who was in charge of spacecraft operations for those machines, said they "won the lottery" as the backup wheel on Anik E1 happened to be removed from the spacecraft for extra testing and it was reworked in a way to make it not susceptible to solar storms. When asked what made the difference, he said he had his suspicions but preferred not to disclose them on the record. (Burlton, interview, 5 April 2012.)

Nick Martens, the satellite engineer for Aniks E1 and E2, said he suspected it had to do with how the backup momentum wheel was attached to the spacecraft. When its shield for the electronics chip was installed, the solvent used to install the shield touched the electronics chip controlling the wheel. That leftover solvent provided a ground when the solar storm hit the spacecraft and stopped the electronics, which were mounted on the outside of the spacecraft, from shorting out. “That's the reason we didn't lose both spacecraft,” he said. In Aniks F1, F2 and F3, the electronics were placed on the inside to prevent that situation from happening again. He added that some other satellites did have the electronics on the inside, but could not comment on industry practices at the time. (Martens, interview, 28 March 2012).

When asked about how Anik E1, Anik E2 and other satellites could have been protected from such a storm, Boteler pointed out there is a trade-off between offering shielding for a spacecraft, which makes it massive, and reducing the mass of a spacecraft to conserve fuel for the launch. Tradeoffs are common in satellite engineering and many of these determinations can only be made through experience, he said. While he had trouble recalling specific missions that have been affected by solar storms, he said there was a Japanese mission to Venus that had a Canadian instrument on board and had been affected by a solar storm. (Boteler, *ibid*.) The author attempted to locate a description of the spacecraft, and believes that Boteler was actually referring to the spacecraft Nozomi, which was bound for Mars in 2002 when it was hit by a solar storm. Carrying a Canadian thermal plasma analyzer on board, the spacecraft was hit by the storm in April (Canadian

Space Agency, 2003). After initial problems with communications and power systems, the hydrazine fuel on board the spacecraft froze due to a short in a power cell that was intended to heat the attitude control system. Two subsequent maneuvers near Earth were successful due to the spacecraft's distance to the sun, NASA determined, as the heat allowed the fuel to thaw. However, a December 14 burn close to Mars (which is further away from the Sun) failed. (National Aeronautics and Space Administration, 14 May 2012).

Despite advances in understanding about solar storms through experience, Boteler said it's quite possible a similar incident could happen today given how circuitry is designed.

> There's a general trend working against them because, as you know, with all the consumer electronics, the trend is to go lower power systems and smaller systems. Well, the satellite electronics is going the same way. So that means you are working with circuits that have lower voltages and you are moving smaller amounts of charge in the circuits to convey the signal. So it means that if you get an extra bit of charge that is dumped in from outside, then that's going to have a significantly larger effect on the new circuits than on the old ones. And I know that that's an issue that the spacecraft industry has been thinking about for a long time ... so I assume that they are adding extra shielding on the circuits and things like that to cope with that. (Boteler, *ibid*.)

Long after the uproar with Canadian broadcasters died down, Telesat was in a crisis. The company would find itself flirting with bankruptcy as the satellite crisis deepened, but what is more interesting is how Telesat pulled out of that difficult situation.

CHAPTER VI: ANIK E2 RECOVERY

As soon as possible after the crisis occurred, Telesat president Larry Boisvert came back from vacation – he was in Hawaii at the time and needed to fly back to Ottawa from there. According to Bruce Burlton, who was in charge of Anik E1's and E2's operations at the time, Boisvert informed the employees that the company was burning a lot of money keeping the signals working for its customers. He urged the employees to get to work as fast as they could, for Telesat's very future was at stake.

> We are begging, borrowing, stealing, leasing whatever capacity on other people's spacecraft ... In relatively short order, the company was going to be bankrupt. We couldn't go on for too long. Essentially renting someone else's infrastructure to do the job, we had spent hundreds of millions of dollars to do ourselves ... If we didn't get it fixed in a few months, we would go bankrupt as kind of the bottom line. So, talk about pressure. (Burlton, interview, 5 April 2012)

After Anik E2 failed, a Canadian bank – the name was withheld by Telesat – froze Telesat's $200 million line of credit, forcing Telesat to ask its stakeholders for help until Banque Nationale du Canada stepped in. "If it wasn't for the shareholders, we would not have survived Anik E2," then chief executive Larry Boisvert said in one media report. (Kainz, 1994). The company lost $15 million as a result of the incident.(Hughes, 1994).

Telesat did insure the Anik E2 satellite (Kurland, 1993), but the challenge was it would take several years to build the new satellite, since manufacturing, testing and other processes take some time, noted Burlton. Also, launching an insurance claim takes time, especially if – as the company discovered in the early days – Telesat could not prove exactly what had happened. (Burlton, personal communication, 30 May 2012.)

In a sense, the controllers needed to work with limitations in the design of the spacecraft to set up a system to control it. Initially designed as a momentum-biased satellite with two momentum wheels, the wheels were intended to provide pitch control. Control for roll, yaw and nutation damping was provided by magnetic torquers. With the wheels gone on Anik E2, the satellite could not control its pitch and maintain pointing control. (Shankar & Goodzeit & Schmidt & Burlton, 1995).

Three challenges faced those looking to rescue the satellite. First, Anik E2 had gyros that were designed to be operated intermittently. Second, with the spacecraft in the incorrect attitude and in a poor spot to receive and transmit signals, it was hard to get a sense of how the spacecraft was moving because of the transmission noise. Noise requires filtering, which requires bandwidth, which takes away the ability to use the available bandwidth for other functions such as providing stability. Finally, even though thrusters appeared to be the best way of controlling the spacecraft, excessively using them would use up fuel and shorten Anik E2's design life. (*Ibid.*) Since the company was not in a financial position to launch another satellite, this consideration was very important to bear in mind.

According to Barry Turner, Telesat had an emergency team (already in place before the Anik E2 incident occurred) including a cross-section of engineers, senior managers, lawyers and other representatives from various divisions of Telesat. During a crisis, the emergency team had de facto authority, similar to Mission Control in NASA. Although the CEO and senior management was not present during the worst of the crisis, the team was able to take command and take control of the situation to the extent that customers began to see service restored, the satellite was configured so it would not do any more harm to itself, and the organization was able to start focusing on the next challenge, which was restoring Anik E2's functionality. During the coming months, a team representing about 10 per cent of Telesat's employees worked full-time on the situation. Presumably, this allowed the more senior managers to focus on running the company while the team worked directly on restoring the satellite. As events were to prove, this worked.

Beyond the fortunes of the company, Telesat was also in a race to prevent the satellite from going dead. According to Burlton, the satellite would periodically be in eclipse by late February. Because of the way the satellite was oriented as it spun, it would not be able to generate as much power as before. This put the orientation of the spacecraft at risk. If that was disrupted, the satellite would "fall over", get cold and possibly experience system failures. Telesat had three "tiger teams" made up of employees and its subcontractors. It was one team's entire job to put the satellite in a safe mode during the repair, while the other two probed the cause of the malfunction and examined potential methods to restore the satellite's functionality. When standing in the shower one day, Burlton conjectured it was possible to orient the spacecraft differently by changing the rotation axis parallel to the axes of the communication antennas. When the team placed the satellite in this attitude, it was now in a stable configuration. The negative side was that communications was poor, since the antennas were not placed in the best attitude to receive and transmit, but the need for stability overrode that consideration.

In addition, the company offset the satellite's two solar arrays in a way that looked similar to a propeller: one was rotated clockwise, and the other counter-clockwise. Any of the particles streaming from the sun that hit the spacecraft would cause a small force, but that would be offset by the orientation on the other solar array. “So arguably, the thing is called solar sailing. By putting it into that attitude, we solved our thermal problem. We solved our thermal problem, solved our power problem and solved the control problem.” (Burlton, *ibid*.) From then on, Anik E2 operated with minimal attitude intervention from the engineers.

Now the engineers needed to figure out how to measure the angular rates in roll, pitch and yaw on the satellite so they could tell Anik E2 where to point. An inertial sensor on board determined pitch and roll automatically; in fact, there was even a backup if that failed. (Burlton, *ibid*.) According to Burlton, all of the signals from the spacecraft were linearly polarized. There were two sets, with one set vertically polarized (along the long axis of the spacecraft) and the other horizontally polarized, at 90 degrees to the first. This was so the controllers could reuse the spectrum, allowing for more capability and traffic. The controllers determined they could figure out the tangent of the yaw of the spacecraft by measuring the relative positions of these two sets of polarized signals. (Burlton, *ibid*.) The final solution came through an interplay between Telesat and General Electric (originally RCA, before a 1986 merger) engineers, he added: “Between us and the folks from RCA, we came up with the concept. Some of our engineers came up with the yaw measurement and technique. RCA came up with some control concepts and we did the rest of it."

The satellite needed to be controlled from the ground, so Telesat put in two sets of yaw sensors, one for each spacecraft, at its control stations in Allen Park (near Owen Sound, Ont.) and Edmonton, an expensive process. According to Burlton, roll and pitch would be received every two seconds, and the yaw sensor would produce data once a second. Every 32 seconds, the computer would then examine the data and make a "control decision" to decide if any corrective action was needed. A typical corrective fire, when required, would last about 10 milliseconds. (Burlton, *ibid*.) The concept was in place by late March, but it took several months more for everything to be ready for flight testing, Burlton recalled.

The satellite was fully recovered by June 21, and commercial service began on July 29, according to Martens. The time in between was used to verify the stability of the system and perform north-south maneuvers to ensure the spacecraft was ready for service. (Martens, *ibid*.) By early 1995, the engineers involved in the rescue were optimistic for the satellite's future. "The spacecraft is in commercial service, and is likely to reach the goal of achieving close to normal operating life," they wrote in a journal article. (Shankar & Goodzeit & Schmidt & Burlton, *ibid*.)

Telesat therefore had fixed the problem.

CHAPTER VII: CONCLUSIONS

The Anik E2 incident had a marked effect upon Canadian broadcasting. Outages took place across the major networks for up to an hour in the more populated areas, and more importantly, several days in northern regions. This meant that people who lived in more remote areas did not get access to broadcast news of the day, including stocks, sports and political news.

In this case, Telesat failed. The company's raison d'être was to serve the northern regions of Canada. When Anik E2 failed, it took days to weeks for the CBC in smaller markets to reposition their antennas to receive Anik E1's signals, all at substantial costs to the broadcaster. The *Globe and Mail* was sending planes out to various communities to deliver its newspapers, again at great cost to the company. In the age of early Internet service, this meant that thousands of people in the north had their news either removed or reduced for several days or weeks.

It should be pointed out, though, that the errors made were of omission and not of commission. The effects of solar storms were not as widely understood then as they are today. Telesat had oversight during the manufacturing process that, although it was not perfect, demonstrated the capability to catch errors as they occur. In addition, the company had an effective management structure that allowed it to work through a crisis even though the senior managers were mostly not present on the day Aniks E1 and E2 malfunctioned. This allowed for customers to be informed quickly and for the company to move signals from Anik E2 to Anik E1 within the first day of the crisis. Although the smaller customers were not served right away, the larger and more urgent ones were. This meant that the Canadian broadcast system did not face a long-term crisis due to Telesat's actions. In fact, it was quite the opposite: the system carried on.

Telesat itself faced a major financial crisis during this time, which cannot be overstated. The company came to the brink of bankruptcy; indeed, its employees were told quite frankly that Anik E2, should it fail completely, would drag the company into oblivion. To the credit of the employees, they carried on and focused on the job at hand, which was fixing the satellite. Six months, as stated earlier in this thesis, was a long time for the satellite to be out of service, but the amount of work involved to bring it back online was extraordinary. From the interviews of Telesat employees, it is clear that they had respect for their immediate superiors and were willing to put in the work necessary to help the company survive. This is especially interesting given that they had just gone through two rounds of major layoffs under their owner at the time, BCE.

The policy implications of Telesat's Anik E2 crisis require further study. It is unclear how supportive the Canadian government was of trying to help the troubled company through scanning the official transcript of Parliamentary discussions (Hansard) and looking at contemporary media reports.

Given the taste for privatization, it is entirely possible the government would have just told Telesat and BCE that they would need to eat the costs and carry on. That said, if the crisis had dragged on for several months, the government would have more likely urged action to address the situation.

In summary, Anik E2 left a mark upon Canadian broadcasting that should not be forgotten. It demonstrates how vulnerable the system was to a rogue solar storm, a vulnerability that is still true of our satellites today. Satellite engineers need to carefully examine past solar storms and their effects on satellites to build the strongest machines possible to withstand them, even in the case of “smallsats” that are the trend today. Since repairing satellites is not a viable option at this time, we need to build the best ones possible and have the greatest means of recovery available to ensure their continuance for time-critical operations, even during moments such as solar storms.

The sun will continue to shine on for the next five billion years. It is up to humans to know how to effectively manage its energy for space exploration. In a sense, the sun is the earth's master. Our appreciation of how to protect our infrastructure against its energy will serve us well. It is only through studying incidents such as this one that we can begin to understand how to stop it from happening again in the future.

Let's hope this next solar maximum brings a minimum of satellite disruptions.

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