A

الأمم المتحدة

الجمعية العامة

Distr.
GENERAL

A/AC.105/611
2 November 1995
ARABIC
ORIGINAL: ENGLISH

لجنة استخدام الفضاء الخارجي
في الأغراض السلمية

السواتل الصغيرة للغاية والسواتل الصغيرة : المشاريع الجارية واحتمالات التعاون الدولي في المستقبل

مذكرة من الأمانة العامة

١ - اقترح الفريق العامل الجامع لتقييم تنفيذ توصيات مؤتمر الأمم المتحدة الثاني المعني باستكشاف الفضاء الخارجي واستخدامه في الأغراض السلمية (يونيسبيس ٨٢) ، في دورته الثامنة (A/AC.105/571 ، المرفق الثاني ، الفقرة ١٧) ، أن يعد مكتب شؤون الفضاء الخارجي عدة دراسات عن التطبيقات الفضائية في ضوء التوصيات التي اعتمدت في حلقات العمل والحلقات الدراسية والندوات والمؤتمرات التي نظمها برنامج الأمم المتحدة للتطبيقات الفضائية . وحدد الفريق العامل الجامع عددا من المواضيع التي يمكن أن تتناولها تلك الدراسات ، منها السواتل الصغيرة للغاية والصغيرة : المشاريع الجارية واحتمالات التعاون الدولي في المستقبل .

٢ - واعتمدت اللجنة الفرعية العلمية والتقنية تقرير الفريق العامل الجامع في دورتها الحادية والثلاثين (A/AC.105/571 ، الفقرة ٢٢) ، أما التوصيات الواردة فيه فقد أقرتها لجنة استخدام الفضاء الخارجي في الأغراض السلمية في تقريرها عن دورتها السابعة والثلاثين ،(١) والجمعية العامة في قرارها ٣٤/٤٩ المؤرخ في ٩ كانون الأول/ديسمبر ١٩٩٤ .

٣ - وقد أعدت الأمانة العامة هذه الدراسة تلبية لطلب من الفريق العامل الجامع . والدراسة متوافرة باللغة الانكليزية فقط ، وترد في مرفق هذه المذكرة . والغرض من الدراسة هو تقديم نبذة عن الميدان السريع التطور للساتلات الصغيرة ، التي هي سهلة المنال حتى للبلدان ذات البرامج الفضائية المحدودة أو التي بدأت حديثا . وقد أعدت الدراسة باستخدام طائفة متنوعة من المصادر الوطنية والدولية ترد في ثبت المراجع المدرج في نهاية الدراسة . وقد أرسلت الدراسة في شكل مسودة الى خبراء خارجيين للتعليق عليها . ويرد فيما يلي ملخص للدراسة .

ملخص الدراسة

٤ - سبق لمنظمات كثيرة استخدام السواتل الصغيرة بنجاح كبير . والسبب في جاذبية هذه السواتل هو أنها يمكن أن تكون زهيدة التكلفة وأن تطور في وقت قصير ، ويتسنى ذلك باستخدام معدات وتقنيات قياسية مجربة ، على أن تكون التوقعات المتعلقة بأدائها توقعات واقعية . وقد بدأ عصر الفضاء باطلاق سواتل علمية صغيرة في عام ١٩٥٨ ، وهي السنة الجيوفيزيائية الدولية . وكانت تلك السواتل صغيرة لأن قدرة مركبات الاطلاق الأولى كانت محدودة . وبعد بداية متواضعة بسواتل صغيرة بسيطة خفيفة ، تطورت النظم الفضائية لتصبح منصات فضائية معقدة ومكلفة مكرسة للبحث العلمي وغيره من التطبيقات ، كثيرا ما يحتاج تطويرها الى سنوات عديدة قبل اطلاقها .

٥ - ومع أن هذه المنصات الكبيرة موجودة وستظل موجودة ، فقد نشأ مؤخرا اهتمام متزايد بالعودة الى استخدام السواتل الصغيرة ، التي يمكن اطلاقها بعد سنوات قليلة من بدء البرنامج . ونتيجة لتطور التكنولوجيات ذات الصلة بالفضاء ، يمكن لهذه الطبقة من المركبات الفضائية أن تتيح قدرات فضائية كبيرة لعدد كبير من المستعملين ، تمتد من الطلاب في المدارس الثانوية والجامعات الى المهندسين والعلماء في كل بلدان العالم . والمشاريع التي تستخدم السواتل الصغيرة مناسبة على نحو مثالي ، من جوانب عديدة للتعاون الدولي الواسع النطاق .

٦ - ولن يحل صنع السواتل الصغيرة محل صنع السواتل الكبيرة ، لأن الأهداف والمسائل المعنية تختلف في كثير من الأحيان . غير أن الرحلات التي تستخدم فيها السواتل الصغيرة يمكن أن تكون مكملة لرحلات السواتل الكبيرة . ويمكن للسواتل الصغيرة ، باستكشاف الجديد من الطرائق والتقنيات ، أن تكون أداة لتجارب وتقنيات رائدة لرحلات مقبلة تستخدم فيها سواتل أكبر .

٧ - وللسواتل الصغيرة عدة مزايا على السواتل الكبيرة ، وتظل هذه المزايا قائمة أيا كان المستعملون . فهي تتيح الفرصة للاضطلاع برحلات أكثر تواترا وتنوعا ؛ ولتوسيع قاعدة المعارف التقنية بسرعة أكبر ؛ ولمشاركة أكبر من جانب الصناعة المحلية ؛ ولزيادة تنوع المستعملين المحتملين . وعلاوة على ذلك ، يمكن حتى لبلد ذي ميزانية بحث متواضعة وخبرة قليلة أو معدومة في تكنولوجيا الفضاء أن يتحمل تكاليف المشاركة في رحلات تستخدم فيها السواتل الصغيرة . وتتيح السواتل الصغيرة أيضا فرصا ممتازة لتدريب الطلاب والمهندسين والعلماء في مختلف التخصصات ، مثل الهندسة ، ووضع البرامجيات للحواسيب المحمولة على متن السواتل والمقامة على الأرض ، وادارة البرامج التقنية المعقدة .

٨ - وبفضل التقدم التكنولوجي الذي أحرز مؤخرا في كثير من الميادين يمكن للسواتل الصغيرة أن تقدم خدمات لم تكن يتيحها في الماضي سوى سواتل أكبر كثيرا . ويمكن بتكاليف متواضعة أن تطلق في الفضاء تجارب علمية وتكنولوجية ، وكذلك رحلات تطبيقية ، معقدة الى حد بعيد . وتشمل مجالات التطبيق الفيزياء الفضائية ، وعلم الفلك ، والفيزياء الفلكية ، والتجارب التكنولوجية

الايضاحية ، وتجارب الاتصالات ، وتحصيل بيانات الموارد الأرضية بما فيها المعلومات المتعلقة بالكوارث .

٩ - وتتفاوت تعاريف الساتل الصغير ، ولكن يؤخذ عادة بحد أقصى للوزن يبلغ ٤٠٠ كيلوغرام (وفي حالات استثنائية ٥٠٠ كغم) ، وتدخل في نطاقه فئتان هما : السواتل الصغيرة ، التي يبلغ وزنها نحو ١٠٠ - ٤٠٠ كيلوغرام ؛ والسواتل الصغيرة جدا ، التي يقل وزنها عن ١٠٠ كيلوغرام . وعموما تكلف "رحلة الساتل الصغير" المعتادة ، بما فيها الاطلاق ، أقل من ٢٠ مليون دولار من دولارات الولايات المتحدة ، ويكلف معظم مشاريع السواتل الصغيرة جدا نحو ٣ ملايين من دولارات الولايات المتحدة .

١٠ - ومن المسائل الجوهرية في أية رحلة لساتل صغير مسألة التوازن الأمثل بين تعقد البرامج وعنصر المخاطرة . ويمكن للسواتل الصغيرة أن تتيح فرصا جديدة في طرائق الاشتراء . والفلسفات المختارة لصنع النماذج مهمة من حيث المخاطرة ومن حيث التكلفة على السواء ، وأقصى ما يكون مقبولا في هذه البرامج هو اتباع نهج الرحلة التجريبية . ومزايا السواتل الصغيرة هي ما يلي :

(أ) امكانية تحديد الأبعاد المدارية بحيث تناسب متطلبات كل جهاز على حدة أمثل تناسب ؛

(ب) تعزيز البرامج الساتلية التقليدية ، مثل القدرة الاضافية ، أو توافر أجهزة بديلة في حالة المهام الحرجة ، أو استبدال الأجهزة المتعطلة عن العمل ؛

(ج) امكانية القيام برحلات ذات احتياجات محدودة من حيث العمر و/أو التغطية ؛

(د) الاستجابة على نحو أفضل لاحتياجات المستعمل النهائي (وجود فرص أكثر للاطلاق ، ومرونة أكبر في الرحلة من حيث المهام التي يمكن أن يقوم بها كل جهاز على حدة ، زائدا استقلالية الجدول الزمني) ؛

(هـ) سرعة الاستجابة ، وامكانية الاطلاق عند الطلب باستخدام مركبات مكرسة زهيدة التكلفة (مثلا لرصد الأزمات ، أو لاستبدال الأجهزة اذا أصيبت بعطل وهي في المدار ، أو لرصد الظروف البيئية غير المتوقعة) ؛

(و) امكانية التسامح في درجة المعولية المطلوبة بالنظر الى قصر عمر الساتل ، أو الاتفاق على أن تكون مستويات ضمان المنتجات أقل أو نوعية الأجزاء أدنى ، حسب الاقتضاء ، بغية تخفيض تكاليف الصنع ؛

(ز) تعقد تصميم الساتل أقل (مثلا استخدام وصلات بينية أبسط ، مصممة لتناسب احتياجات الأجهزة على الوجه الأمثل) ، والفترة الزمنية اللازمة لصنعه أقل ، كما تتيح هذه السواتل مجالا مناسبا لتجربة التقنيات و/أو التكنولوجيات .

١١ - وهناك ثلاثة أصناف عامة من المدارات يمكن أن تكون مناسبة للسواتل الصغيرة ، وهي : المدار الثابت بالنسبة الى الأرض ، والمدار الشديد الاهليلجية ، والمدار الأرضي المنخفض .

١٢ - والمدار الثابت بالنسبة الى الأرض هو المدار الذي يبدو فيه الساتل ثابتا بالنسبة الى الأرض ، مما يتيح استمرارية الرؤية ويبسط احتياجات التشغيل والعنصر الأرضي . بيد أنه ، بسبب المسافة الكبيرة من الساتل في الفضاء الى الأرض ، تكون معدلات نقل البيانات ضئيلة ، أو تلزم هوائيات أرضية أكبر وطاقة كهربائية أعلى على متن المركبة الفضائية . ويتم الوصول الى هذا المدار عادة من مدار انتقالي قياسي ثابت بالنسبة الى الأرض ، يمكن الوصول اليه بواسطة مركبة اطلاق كبيرة .

١٣ - واستخدام المدار الانتقالي الثابت بالنسبة الى الأرض مسألة مثيرة للاهتمام ، حيث يمكن أن يستفاد فيه من الفرص المتواترة لاطلاق السواتل الرديفة (piggyback) مع تفادي ما يرتبط بنظام الدفع الأوجي من تعقد وتكاليف اضافية .

١٤ - وعادة ما يفضل لرحلات السواتل الصغيرة المدار الأرضي المنخفض . ذلك لأنه يمكن استخدام مركبات اطلاق صغيرة ، تتيح المرونة في اختيار الأبعاد المدارية ؛ ويمكن أيضا اللجوء الى اطلاق السواتل الرديفة . ويكفي أن يكون على متن الساتل جهاز ارسال يعمل بطاقة منخفضة ، بالنظر الى قصر المسافة الى الأرض ، ولكن توجد مثلبان هما قلة معدل تواتر فترات الرؤية وقصرها ، مما يؤدي الى بعض التعقد في العنصر الأرضي وفي التشغيل . وينبغي التمييز بين المدارات القريبة من خط الاستواء أو المنخفضة الميل ، التي تقتصر فيها منطقة الرؤية على المنطقة المحلية ، والمدارات القطبية أو شبه القطبية (المتزامنة مع الشمس) ، التي تسمح بالنفاذ الى أية نقطة على الأرض ، إما للاتصال (مثلا لتخزين البيانات ثم نقلها) أو لاستشعار الأرض عن بعد .

١٥ - ويرتبط تطوير السواتل الصغيرة ، في الحاضر والمستقبل ، ارتباطا وثيقا بظهور مركبات اطلاق جديدة زهيدة التكلفة (مثل بيغاسوس وتوراس وغيرهما) ، وفرص اطلاق أقل تكلفة على المركبات الحالية (مثل اريان - ٤ ، أو في حاويات صغيرة على متن المكوك الفضائي) . وكانت امكانية توافر مركبات اطلاق رخيصة هي الحافز على قدر كبير من ازدياد الاهتمام بالسواتل الصغيرة الذي جرى مؤخرا ، والذي كان الدافع اليه في البداية هو أساسا برامج الدفاع والاتصالات المدنية العالمية التابعة للولايات المتحدة الأمريكية . ومركبتا الاطلاق بيغاسوس وتوراس هما الوحيدتان اللتان جرب طيرانهما بنجاح من بين مركبات الاطلاق الرئيسية الزهيدة التكلفة التابعة للبلدان الأوروبية والولايات المتحدة . ويعتزم اطلاق المركبة كونيستوغا في المستقبل القريب ، ولم يبدأ بعد تطوير المركبة الايطالية سان ماركو سكاوت بعد (وان كانت سليفتها مركبة الولايات المتحدة سكاوت تعمل منذ سنوات عديدة) ، وينبغي انجاز في عام ١٩٩٥ برنامج آريان - ٥ المشتق .

١٦ - ومن أجل بلوغ أقصى حد لامكانيات مركبات الاطلاق الصغيرة ، ينبغي للمضطلعين بتطويرها أن يستخدموا نفس نهج التصميم الابتكاري الزهيد التكلفة المتبع في السواتل الصغيرة . فتكاليف

الاطلاق تمثل نسبة كبيرة من التكاليف الكلية للبرنامج (تزيد عموما على ٢٥ في المائة) ولذلك يجب الحد من كتلة الساتل وحجمه بغية الاستفادة تماما من فرص الاطلاق الزهيدة التكلفة . ومن الخيارات المتاحة ما يلي :

(أ) مركبات الاطلاق الصغيرة المخصصة ؛

(ب) اطلاق عدة سواتل صغيرة على مركبة اطلاق واحدة ، أي على الساتل آريان - ٤ أو الساتل آريان - ٥ الخاصين بالرحلات الأوروبية (مثل اطلاق السواتل العلمية المحتشدة التابعة للوكالة الفضائية الأوروبية (الايسا)) ؛

(ج) امكانية اطلاقها بواسطة مركبات الاطلاق الكبيرة روجت مؤسسة آريان الفضائية (آريان سبيس) ترويجا شديدا لاستخدام مركباتها لهذا الغرض ، وتتيح المركبة آريان - ٤ ما يلي : هيكل آريان للحمولات الاضافية ، للسواتل الصغيرة جدا الرديفة (بحد أقصى ستة سواتل وزن كل منها ٥٠ كيلوغراما (المجموع ٣٠٠ كيلوغرام)) ؛ وتشكيلة من نوع الساتل الفرنسي آريان لهواة الارسال اللاسلكي (ارسينه) ، للسواتل التي لا يزيد وزنها على ٢٠٠ كيلوغرام ؛ والسواتل المخصصة "سبيلدا" (هيكل آريان ذو المحامل الخارجية الخاص بالاطلاق المزدوج) ، الخاصة بالسواتل التي يتراوح وزنها بين ٤٠٠ كيلوغرام و ٨٠٠ كيلوغرام والمحمولة داخل مهايىء سبيلدا القصير .

١٧ - وتتيح مركبات اطلاق أخرى متوسطة الحجم أو كبيرة ، مثل مركبتي الولايات المتحدة أطلس سنتور ودلتا - ٢ ، خيارات مماثلة .

١٨ - وتتفاوت متطلبات القطاع الأرضي لنظام السواتل الصغيرة تفاوتا هائلا ، على حسب مجال التطبيق ، ففي أحد الطرفين ، هناك أجهزة الاستشعار ذات معدل نقل البيانات المنخفض والتغطية المحلية أو الاقليمية فقط ، المستخدمة في الرحلات ذات الاحتياجات المنخفضة من حيث التتبع والتحكم ، ولا تقتضي هذه الأجهزة سوى القليل من المتطلبات على القطاع الأرضي ، يحتمل أن تشكل ١٠ في المائة فقط ، أو أقل ، من تكاليف البرنامج الكلية . ويمكن أن يترتب على زيادة تعقد متطلبات استرداد البيانات ومعالجتها أن تصل تكاليف القطاع الأرضي الى ٥٠ في المائة من التكاليف الكلية للبرنامج . وبافتراض أن تكاليف القطاع الأرضي تشكل عادة في المتوسط ٢٥ في المائة من تكاليف البرنامج الكلية ، تتضح أهمية تحديد الوفورات التي يمكن تحقيقها في القطاع الأرضي ، وتتسق مع الوفورات التي يمكن تحقيقها في القطاع الفضائي .

١٩ - وفي محاولة تخفيض تكاليف القطاع الأرضي ، توجد حدود للتبسيط ، لأنه يظل يلزم ضمان تحقيق قدرات مثل معولية التشغيل ، وسرعة الاستجابة للمتطلبات الحرجة ، وانتظام شكل البيانات مع ورودها في الوقت الملائم وبنسبة فقدان منخفضة . ونموذج القطاع الأرضي ، الذي يشكل أساس أي تقييمات تقنية أو تقييمات للتكاليف ، يجب ألا يشتمل على توفير المحطات الأرضية فحسب بل يجب أن يشتمل أيضا على توفير الهياكل الأساسية الخاصة بالاتصالات الأرضية ، والتحكم في الرحلات ،

الخ . وقد وفر عدة موردين في البلدان الأوروبية وفي الولايات المتحدة ، على أساس تجاري ، محطات صغيرة للغاية ، وأحيانات متنقلة . ويحتمل أن تلح الجهات التجارية التي توفر بيانات الاستشعار عن بعد على اعتماد هذه النهوج في محاولات تخفيض تكلفة توزيع البيانات ومعالجتها .

٢٠ - ومن الواضح أن أنشطة علوم الفضاء أنشطة قيمة ، وقد بدأ معظم الأمم المرتادة للفضاء مشاركته في هذا الميدان بسواتل علمية صغيرة . وكثيرا ما يكون الوسط الجامعي بيئة مثالية لتطوير الأنشطة الفضائية ، وبما أن هذه المشاريع تتطلب في كثير من الأحيان انشاء مختبرات جديدة فان هذه المرافق نتاج ثانوي نافع يترتب على هذه المشاريع . وبذلك تبدأ الفوائد الجانبية الناجمة عن البرنامج الفضائي ، وهي اقتناء التكنولوجيا وتطوير أساليب الادارة والتنظيم الصناعي ، تتجمع على الصعيد الوطني مع تخرج الطلاب من الجامعات وعملهم في الصناعة المحلية .

٢١ - وسيكون أول ساتل علمي صغير للأرجنتين هو ساتل التطبيقات العلمية (ساك - باء SAC-B) ، الذي يجري صنعه بالاشتراك مع الوكالة الفضائية الوطنية للأرجنتين ، وهي اللجنة الوطنية للأنشطة الفضائية (كوناي - CONAE) ، والادارة الوطنية للملاحة الجوية والفضاء (ناسا) التابعة للولايات المتحدة . ويزن الساتل ١٩٠ كيلوغراما ، وسيطلق في عام ١٩٩٦ بصاروخ من طراز بيغاسوس الى مدار دائري ارتفاعه ٥٥٠ كيلومترا وبميل يبلغ ٣٧ درجة . وسيحقق استقرار الساتل ساك - باء بواسطة القصور الذاتي ، وسيكون متجها نحو الشمس على الدوام . وسيرصد الساتل اشعاعات الطاقة السينية الصادرة عن التأججات الشمسية ، وسيمسح السماء ، أجهزة الاستشعار الأشعة السينية مزودة بجهاز متقارن بواسطة الشحنات ، على محور متعامد على خط الاتجاه الشمسي .

٢٢ - وفي الفترة بين عام ١٩٧٨ وعام ١٩٩١ ، طورت سواتل علمية صغيرة جدا ، وزنها ١٥ - ٥٠ كيلوغراما ، لبرنامج أبحاث الغلاف المغنطيسي - الغلاف المتأين (ماغيون - MAGION) في تشيكوسلوفاكيا السابقة . وأطلق الساتل ماغيون - ١ في ٢٤ تشرين الأول/أكتوبر ١٩٧٨ بصفته ساتلا رديفا للساتل انتركوزموس - ١٨ الجيوفيزيائي . وعلى الرغم من أن الساتل ماغيون - ١ كان مصمما بحيث يكون عمره التشغيلي ثلاثة أسابيع فانه ظل يعمل لمدة ثلاث سنوات . وأطلق الساتلان ماغيون - ٢ وماغيون - ٣ الى مدارين شديدي الميل منخفضي الانحراف المركزي (بارتفاع ٥٠٠ - ٢٠٠ ٣ كيلومتر) ، باعتبارهما جزءا من رحلة "اكتيف" (ACTIVE) ورحلة تجربة آريان لحمل الركاب (أبيكس - APEX) الفضائيتين الفاعلتين الترادفيتين اللتين أطلقتا في ٢٨ أيلول/سبتمبر ١٩٨٩ و ١٨ كانون الأول/ديسمبر ١٩٩١ ، على التوالي . وأطلق الساتل الرديف ماغيون - ٤ بنجاح بواسطة مركبة الاطلاق مولنيا (Molniya) من الميناء الفضائي في بليسيتسك ، الاتحاد الروسي ، في ٣ آب/أغسطس ١٩٩٥ ، بصفته جزءا من رحلة إنتربول - تيل (INTERBALL-tail) . ومن المقرر حاليا اطلاق الساتل ماغيون - ٥ في عام ١٩٩٦ .

٢٣ - وساتل أوروبا الوسطى للأبحاث المتقدمة (سيزار - CESAR) هو مركبة فضائية تزن نحو ٣٠٠ كيلوغرام ستحلق في مدار حضيضه ٤٠٠ كيلومتر ، وأوجه ٠٠٠ ١ كيلومتر ، بانحراف قدره ٧٠ درجة . وتتعلق الرحلة العلمية بدراسة الغلاف المغنطيسي والغلاف المتأين والغلاف الحراري للأرض .

وستحمل المركبة الفضائية عشر تجارب مختلفة ، أعدها علماء من بولندا والجمهورية التشيكية وسلوفاكيا والنمسا وهنغاريا ، وتمول الرحلة الوكالة الفضائية الايطالية (أسي) ، وقد صممها الينياسبازيو. وانجاز هذه الرحلة هو أحد أهداف التعاون بين بلدان مبادرة وسط أوروبا .

٢٤ - وقد اكتسبت مؤسسات الصناعة الفضائية والبحوث الفضائية في فنلندا خبرة في حمولات السواتل وأجهزتها من خلال انتسابها الى الايسا ، وهي نشطة منذ وقت طويل في الاستشعار عن بعد وغيره من التخصصات المتصلة بالفضاء . ولبدء دراسة عن ساتل فنلندي صغير (ف س - ١ - FS-1) ، حددت المؤسسات الفنلندية اهتماماتها بالاتصال بمعاهد مختارة بواسطة اعلان فرصة غير رسمي وبطلب اقتراحات . وبعد مرحلة الاقتراحات ، جرى تصميم النظام لبديلين هما : ساتل علمي ، وساتل لرصد الأرض . وسيحتوي كل ساتل على مجموعة معدات تكنولوجية ايضاحية ستختبر فيها في البيئة الفضائية مكونات الكترونية جديدة .

٢٥ - وينظر المركز الوطني الفرنسي للدراسات الفضائية حاليا في اطلاق السواتل العلمية الصغيرة التالية :

(أ) الرحلة "سامبا" (SAMBA) : تسجيل التذبذبات المحلية للاشعاع الذي يبلغ ٣ "كلفن" الصادر عن الانفجار الكوني العظيم (big bang) (مشابه للساتل "اكسبلورر" المخصص لدراسة اشعاعات الخلفية الكونية ، التابع للولايات المتحدة) ، والقياس التفصيلي لتباين الخواص الممكن ؛

(ب) الرحلة "كوروت" (COROT) : علم الزلازل الفلكي ، وبيانات جديدة عن الحمل الحراري والدوران الداخلي للنجوم ، بواسطة قياسات طويلة الأجل للتذبذبات النجمية ؛

(ج) الرحلة "ايبيزا" (IBIZA) : تسجيل البلازما المتسارعة في مناطق الشفق القطبي المغنطيسية الأرضية ، وتفاعل الجسيمات المؤينة مع الغلاف المتأين والغلاف المغنطيسي للأرض ، وتكوين الاضطرابات الكهرمغنطيسية ؛

(د) "الخطوة السريعة" (QUICK-STEP) : التحقق من تكافؤ كتلة القصور الذاتي وكتلة الجاذبية (نظرية النسبية) ، بدقة نسبية قدرها ١٠-١٧ .

٢٦ - وفي ٣ شباط/فبراير ١٩٩٤ ، حمل الساتل الصغير "بريمسات" (BREMSAT) التابع لجامعة بريمين الى مداره بواسطة المكوك الفضائي ديسكفري التابع للولايات المتحدة . وكان وزن الساتل ٦٣ كيلوغراما ، وظل ستة أيام في حاويته المسماة "Get Away Special (GAS)" قبل أن يطلق الى مداره الدائري الأولي على ارتفاع ٣٥٠ كيلومترا . وحمل الساتل ست تجارب ذات أهداف علمية مختلفة ، منها انتقال الحرارة بالحمل في ظروف الجاذبية الضئيلة ، وتوزيع الحجارة النيزكية الدقيقة وجسيمات الغبار الدقيقة ، ورسم خرائط للأوكسيجين الذري الجوي ، والضغوط ودرجات الحرارة لدى العودة الى جو الأرض . وظل الساتل يعمل الى أن تحلل في مداره في ١٢ شباط/فبراير ١٩٩٥.

٢٧ - وأعدت الهند ، لدى تطوير قدرتها الذاتية على اطلاق المركبات الفضائية ، سلسلة من السواتل الصغيرة العلمية والخاصة بتطوير التكنولوجيا تسمى سلسلة سواتل روهيني (Rohini) العلمية وسلسلة سواتل روهيني العلمية الممددة (سروس) . وأطلقت سواتل روهيني بين عام ١٩٨٠ وعام ١٩٨٣ ، وعلى متنها حمولة من أجهزة لاستشعار المعالم الأرضية تشمل آلة تصوير في حالة الصلابة . وتم الحصول على أكثر من ٥٠٠ ٢ صورة ، في نطاقات موجات الأشعة المرئية وتحت الحمراء على السواء من أجل استبانة المعالم الأرضية والارتفاع والضبط الدقيق للمدار . وكانت كتلة سواتل روهيني في المدار نحو ٤٢ كيلوغراما .

٢٨ - وأطلق الساتلان سروس - جيم وسروس - جيم ٢ في ٢٠ أيار/مايو ١٩٩٢ و ٤ أيار/مايو ١٩٩٤ ، على التوالي . ويحمل كل منهما حمولتين علميتين . والحمولة الأولى هي محلل القوة التعويقية ، مؤلف من مكشافين مستويين لقياس أبعاد البلازما ولدراسة البنية الطاقوية للغلاف المتأين الاستوائي . والحمولة الثانية هي تجربة تفجر أشعة غاما ، وتشتمل على مكشافين للبريق لدراسة انفجارات أشعة غاما السماوية في نطاق الطاقة ٢٠ - ٠٠٠ ٣ كيلو - الكترونفلط .

٢٩ - وعهدت الحكومة الأسبانية الى المعهد الوطني للتقنية الفضائية الجوية الأسباني ، الكائن في توريخون دي أردوث ، بتوجيه مشروع بحثي لتطوير نظام فضائي أسباني ، يسمى مينيسات (MINISAT) . وسيتألف النظام من منصة متعددة الأغراض (أنموطة خدمة) ، وأنموطة حمولات ، وقطاع أرضي مرتبط بذلك . والمنصة والنظم الفرعية التي تتألف منها المنصة هي وحدات تجميعية . وستكون المنصة قادرة على استقبال وتجميع وتشغيل وحمل أنموطة حمولات على متنها بواسطة وصلات بينية قياسية . وهذا سيتيح سهولة اجراء جميع عمليات التكييف اللازمة لأية رحلة معنية . وستكون المنصة قادرة على حمل حمولات تتراوح كتلتها بين ٨٠ كيلوغراما و ٥٠٠ كيلوغرام . وسيكون أول هذه السواتل رحلة مينيسات تحمل أنموطة حمولات (PLM-1) .

٣٠ - وكان أول ساتل صنعته السويد هو الساتل فايكينغ الذي يزن ٢٨٣ كيلوغراما ، الذي أطلق الى مدار قطبي منخفض في عام ١٩٨٦ في تشكيلة ترادفية مع الساتل الفرنسي للاستشعار عن بعد المسمى "ساتل رصد الأرض" (سبوت) . وكان الهدف العلمي من الساتل فايكينغ هو دراسة ظواهر الغلاف المتأين والغلاف المغنطيسي على خطوط العرض الجيومغنطيسية العالية في المنطقة التي يصل ارتفاعها الى ما يعادل قطر الأرض تقريبا . وأجريت قياسات متزامنة للمجالات الكهربائية والمغنطيسية وتوزيعات الجسيمات ، وتركيب البلازما والموجات ، كما جرى تصوير تغيرات الشفق القطبي في نطاق موجات الأشعة فوق البنفسجية .

٣١ - وأطلق في ٦ تشرين الأول/أكتوبر ١٩٩٢ بواسطة مركبة اطلاق صينية ساتل علمي صغير أكثر تقدما يسمى فريا . ووزن هذا الساتل ٢١٤ كيلوغراما ، والهدف منه هو اجراء بحوث عن الشفق القطبي وظواهر الغلاف المغنطيسي الأخرى ذات الصلة .

٣٢ - ولأن علماء الغلاف المغنطيسي السويديين شديدو الاهتمام بالامكانيات التي تتيحها السواتل الصغيرة ، فقد صنعوا منصة ساتلية صغيرة تبلغ كتلتها ١٠ في المائة من كتلة الساتل فريا . وهذا الساتل الصغير جدا الجديد ، المسمى آستريد على شكل صندوق مقاييس جوانبه نحو ٥٠ سنتيمترا × ٥٠ سنتيمترا ، وتكون كتلته ٢٥ كيلوغراما في حالة تخزينه . وهو موازن بالدوران ، وله قدرة على التوجه في اتجاه الشمس ، كما له ألواح للطاقة الشمسية قابلة للبسط . وقد أطلق الساتل أستريد الأول في ٢٤ كانون الثاني/يناير ١٩٩٥ من الميناء الكوني في بليسيتسك على مركبة اطلاق من طراز كوزموس .

٣٣ - وأفضل مثال لبرامج السواتل الصغيرة في الولايات المتحدة هو برنامج إكسبلورر الصغير (سميكس) التابع لناسا ، الذي يتيح فرصا كثيرة لاطلاق رحلات علمية ذات مجالات شديدة التركيز وغير مكلفة نسبيا . ويزن كل ساتل من سواتل سميكس نحو ٢٥٠ كيلوغراما ، ويتوقع أن تكلف كل رحلة نحو ٥٠ مليونا من دولارات الولايات المتحدة للتصميم والصنع واجراء عمليات في المدار لمدة ٣٠ يوما . وأطلق أول ساتل من هذه السلسلة ، وهو الساتل إكسبلورر الخاص بدراسة الجسيمات الشمسية والشاذة وجسيمات الغلاف المغنطيسي (سامبيكس) ، في ٣ تموز/يوليه ١٩٩٢ . ولا يزال الساتل يتقصى بنجاح تركيب المادة النجومية المحلية والمادة الشمسية ونقل جسيمات الغلاف المغنطيسي المشحونة الى جو الأرض . وسيطلق الساتل الفلكي الخاص بالموجات دون الملليمترية (سواس) على صاروخ من طراز بيغاسوس في عام ١٩٩٥ أو عام ١٩٩٦ .

٣٤ - وربما كانت أكثر وحدات البحوث خبرة في مضمار السواتل الصغيرة هي وحدة أبحاث هندسة المركبات الفضائية في جامعة سري في المملكة المتحدة لبريطانيا العظمى وايرلندا الشمالية . وقد سجل فريق الساتل يوسات (UOSAT) ، ومنذ فترة أقرب فريق شركة سري المحدودة لتكنولوجيا السواتل ، أكثر من ٢٥ سنة مدارية من تشغيل السواتل الصغيرة منذ سنة ١٩٨١ وحتى الآن . وأطلق بين عام ١٩٨١ وعام ١٩٩٣ ما مجموعه عشرة سواتل في اطار مشروع سواتل جامعة سري (يوسات) . وأطلق في آب/أغسطس ١٩٩٢ الساتل الصغير التشغيلي S-80/T ، المستند الى منصة يوسات ، وكان الهدف من رحلته بحث امكانيات الاتصال التي تتيحها نطاقات الترددات العالية جدا التي كرسها المؤتمر الاداري العالمي للاتصالات اللاسلكية (وارك - ٩٢) لنظم السواتل غير الثابتة بالنسبة الى الأرض . وتحققت المهمة الأولية للرحلة بنجاح . وأكمل الساتل S-80/T سنته التشغيلية الأولى في تشرين الأول/أكتوبر ١٩٩٣ ، ولا يزال يؤدي مهامه دون أي خلل . وتستطيع سواتل هواة الارسال اللاسلكي التابعة لسلسلة يوسات بث صور سطح الأرض وكذلك بث بيانات الأرصاد الجوية .

٣٥ - أحدث اضافات الى مجموعة سواتل مشروع جامعة صري للسواتل (يوسات) هي الساتل التجريبي البرتغالي بوسات - ١ (POSAT-1) وهيلثسات - ٢ (HEALTHSAT-2) وكيتسات - ٢ (KITSAT-2) ، التي أطلقت في أيلول/سبتمبر ١٩٩٣ على متن Ariane V-59 مع الساتل التجاري للاستشعار من بعد سبوت - ٣ . وبوسات هو نتيجة تعاون وثيق بين شركة صري لتكنولوجيا السواتل (المحدودة) واتحاد صناعي برتغالي . وتوجد أوجه تشابه كثيرة بين منصته والستلين S-80/T و KITSAT-1 (اللذين أطلقا في آب/أغسطس ١٩٩٤) ، وقد صنع بعض الحمولات مهندسون من جمهورية كوريا .

٣٦ - وفي ٩ شباط/فبراير ١٩٩٣ أطلق جهاز اطلاق من طراز بيغاغوس أول ساتل برازيلي لجمع البيانات (SCD-1) بميل قدره ٢٥ درجة وارتفاع قدره ٧٥٠ كم . وهذا الساتل ، الذي قام بتصميمه وصنعه المعهد الوطني البرازيلي لبحوث الفضاء (انبيو) هو ساتل مستقر الدوران مخصص لجمع وتوزيع البيانات البيئية التي تحصلها وتبثها منصات جمع البيانات فوق الاقليم البرازيلي . ويعمل هذا الساتل منذ اطلاقه بشكل ممتاز ، والساتل البرازيلي الثاني لجمع البيانات ، وهو يشبه كثيرا الساتل البرازيلي الأول لجمع البيانات ، يمر الآن بمرحلة التجميع النهائية ، وسيطلق في مطلع عام ١٩٩٦ .

٣٧ - والساتل الأول من سلسلة سواتل ايطالية لجمع البيانات يسمى الساتل المصغر الايطالي للبيئة (تيميسات) قد أطلق بجهاز اطلاق روسي من طراز تسيكلون من ساحة اطلاق الأجسام الفضائية في بليسيتسك في ٣١ آب/أغسطس ١٩٩٣ مع ساتل من طراز ميتور - ٢ . ويدور هذا الساتل حول الأرض على ارتفاع ٩٥٠ كم بميل قدره ٨٢ر٥ درجة وانحراف مركزي أقل من ٠ر٠٠٠١ . وصنعت وحدة أخرى (تيميسات - ٢) مع الوحدة الأولى ، وخزنت على الأرض ، ويمكن اطلاقها لزيادة قدرة الخدمة في المدار .

٣٨ - والسواتل الصغيرة التي تستخدم في بعثات رصد الأرض يمكن أن تستعمل بشكل مستقل لأداء مهمة أجهزة محمولة محددة . فيمكن اطلاق مجموعة منها لكي تعزز أو تحل محل مهام ساتل أكبر متعدد الأجهزة . والسواتل الصغيرة لن تحل كلية محل المنصات الكبيرة التي تحقق فوائد مالية وعلمية مثل وفورات الحجم الكبير وتآزر القياسات . وعلاوة على ذلك فان السواتل الكبيرة ضرورية في الحالات التي يتعين فيها أن تكون أجهزة معينة كبيرة بقدر كاف لأداء أهداف البعثة بطاقة كبيرة ومعدلات بيانات مرتفعة للغاية (مثلا على حسب حجم هوائي الرادار أو الأداء الضوئي للفتحة والطول البؤري) .

٣٩ - ومن بين بعثات رصد الأرض الملائمة للسواتل الصغيرة أخذ عينات عالمية للمحيطات (بمجموعة من السواتل) ، وأخذ العينات الجيوفزيائية (بساتل واحد في مدار قطبي) ، والرصد اللوني للمحيطات وللمناطق الساحلية ، وحمل جهاز واحد دعما لبعثات أكبر ، والعمليات التجارية لمسح الأرض ورسم الخرائط ، واطلاق ساتل صغير واحد حسب الطلب أو مجموعة سواتل صغيرة لرصد الأزمات و/أو الكوارث (مثل الفيضانات وطرائق الغابات وحوادث التلوث النفطي) ، ورصد النباتات لأغراض الزراعة والتحريج .

٤٠ - ومشروع ساتل رصد الأرض المتكرر المدار هو مثال لساتل صغير يستخدم لأغراض الاستشعار من بعد . وباستخدام مدار متكرر (بتتبع أرضي متكرر كل خمس عشرة دورة) يتحسن كثيرا تردد رصد المنطقة . وهذا هو أصل مفهوم الساتل المحلي لرصد المنطقة الحضرية (ديوس) .

٤١ - ويعتمد نظام ديوس على ساتل التجربة الهندسية للاتصالات الضوئية فيما بين السواتل ، الذي من المقرر حاليا اطلاقه بجهاز الاطلاق J-1 في عام ١٩٩٨ . وسيكون له موصلة مستقرة ذات ثلاثة

محاور لها لوحين من البطاريات والصفائف الشمسية . وفي حدود الكتل المتاحة يمكن للساتل أن يحمل مقياس الأشعة المرئية والأشعة دون الحمراء الدنيا ومقياس الأشعة دون الحمراء الحراري .

٤٢ - والهدف الطويل الأجل للبرنامج الساتلي لجامعة برلين التقنية (توبسات) هو صنع منصة رصد مستقرة ذات ثلاثة محاور قادرة على التوجيه الذاتي بدقة قوسية متناهية في أي اتجاه واستشعار الأرض من بعد يحظى باهتمام كبير ، ويلزم تحقيق الاستقرار تماما من أجل الرصد وارسال البيانات بمعدل مرتفع لاستقبال الصور في الزمن الحقيقي فعلا أو تقريبا . ويسعى الى تحقيق هذه الأهداف بعدة خطوات .

٤٣ - واستنادا الى الخبرة المدارية المكتسبة فيما يتعلق بالساتلين توبسات - ألف وتوبسات - باء ، اللذين أطلقا في عامي ١٩٩١ و ١٩٩٤ ، على التوالي ، سوف تتضمن أجهزة المركبة الفضائية الثالثة ثلاثة جيروسكوبات ضوئية ليفية تستخدم الليزر . وقد صنع هيكل أولي لتوبسات - جيم يستخدم فعلا لتجارب على تحميل جوي ذي ثلاثة محاور .

٤٤ - وسوف يثبت نظام استطلاع الحرائق السابق للتشغيل (فايرز) جدوى وفائدة نظام ساتلي تشغيلي مستقبلي صغير في استطلاع الحرائق . ويتوقع أن يكون مفيدا لا لمجرد رصد حريق في منطقة كبيرة فحسب بل أيضا لقدرته على تحديد موقع الحريق وتقييم مداه (من حيث الحيز والوقت) ونوع الحريق وتقديم هذه المعلومات الى السلطات المحلية في الوقت المناسب . وعلاوة على هذه المهمة الرئيسية ينتظر أن يكون في مقدور النظام أن يحل مشاكل ثانوية مثل تقييم التلف الذي أصاب النباتات والتلوث الجوي وتقييم انعاش المناطق المحترقة . وفضلا عن ذلك عندما لا يكون الساتل فوق مناطق توجد فيها نباتات فان جهاز الاستشعار الموجود على متنه يمكن أن يسهم في مهام استشعار أخرى متصلة برصد درجات الحرارة المرتفعة .

٤٥ - وقد اقترح أن تنشىء وكالة لا تستهدف تحقيق الربح ، في الولايات المتحدة هي جمعية المتطوعين لتقديم المساعدة التكنولوجية ساتلية صحية بغربي أفريقيا تستخدم مجموعة من سواتل الاتصالات الصغيرة ذات المدار الأرضي المنخفض لربط المراكز الطبية الاقليمية بمستوصفات قروية وفرق صحية متنقلة . وسوف تستعمل هواتف لاسلكية مرسلة ومستقبلة ، عندما يكون ذلك أكثر وفرا ، لربط القرى أو الوحدات المتنقلة بالمستوصفات المحلية ، التي سترتبط بدورها بمركز اقليمي عن طريق السواتل . وقدر أنه يمكن صنع ١٠ سواتل صغيرة للغاية واطلاقها بمبلغ ٢١ مليونا من الدولارات الأمريكية تقريبا ، في حين سيلزم ٣٠ مليونا من الدولارات الأمريكية من أجل المرافق الطبية وشبكة المحطات الأرضية . ويمكن أن يسهم هذا النظام اسهاما هائلا في تحسين حصول السكان الريفيين على الرعاية الطبية الجيدة . وفي حالة نجاح هذه التجربة فانها ستكون نموذجا للمناطق النائية الأخرى .

٤٦ - وقد جعل توافر فرص الاطلاق المنخفضة التكلفة نسبيا في الفترة الأخيرة من الممكن أن تتصور المؤسسات التعليمية قيامها بتصميم ساتل صغير وصنعه واختباره وتشغيله . وهناك دائما تشديد

على ضرورة المشاركة الفعالة لأعضاء المجتمع الجامعي (الأساتذة والطلبة وطلبة الدراسات العليا) ، الأمر الذي يعطيهم خبرة عملية لا تقدر بثمن في تكنولوجيا الفضاء والبحث العلمي .

٤٧ - على سبيل المثال قامت جامعة مدريد التقنية بتصميم وصنع الساتل الأسباني الصغير الأول أبم/سات ١ (UPM/SAT 1) ، التي تبلغ كتلته ٤٧ كغم . وهو منصة منخفضة التكلفة عمرها التشغيلي متوسط الطول ويمكن تطويرها في المستقبل . وقد أطلق هذا الساتل في ٧ تموز/يوليه ١٩٩٥ بوصفه حمولة ثانوية لصاروخ اريان - ٤٠ حمل الساتل الفرنسي هليوس - ١ ألف . والتجربة الرئيسية التي ستجرى على متن الساتل تتمثل في رصد سلوك تشكل للموانع يسمى الجسر الساتل في ظروف الجاذبية الضئيلة ، وان وضع تصميم على درجة متوسطة من التعقد في بيئة جامعية من شأنه أن يتيح للأساتذة والطلبة اكتساب الخبرة اللازمة للمشاريع الأكثر تعقدا .

٤٨ - ومن المقرر أن يطلق في أوائل عام ١٩٩٦ ساتل صنست (Sunset) الذي يقوم بتصميمه حاليا طلبة الدراسات العليا في قسم الهندسة الالكترونية في جامعة ستلنبوش في جنوب أفريقيا . وهو ساتل صغير وزنه ٥٠ كغم يمكن اطلاقه بجهاز اطلاق من طراز اريان ويمكنه التقاط الصور المجسمة للأرض بثلاثة ألوان . ويمكنه ارسال الصور في الزمن الحقيقي أو تخزينها على متن الساتل . ويمكن التحكم في ارتفاع الساتل في حدود مليراديان واحد . وتتضمن مجموعة الاتصالات خط للاتصال بالأرض على النطاق S واتصالات خزن فارسال لراديو الهواة مع معيد سمعي لحفز الاهتمام باللاسلكي فيما بين أطفال المدارس .

٤٩ - وقد كانت فرص الدخول في الأنشطة الفضائية على مستوى ذي معنى في الماضي محدودة بالنسبة الى البلدان الصغيرة والمتوسطة الحجم . بيد أن أوجه التقدم التكنولوجي في المواد والالكترونيات الصغرية مع الخبرة المكتسبة في العقد الماضي قد أتاحت أداء بعثات فضائية مهمة كثيرة بسواتل صغيرة . واعترافا بما لهذا الاتجاه من أهمية للتعاون الدولي في الفضاء الخارجي رفعت الأكاديمية الدولية للملاحة الفضائية ، في اجتماعها المعقود في آب/أغسطس ١٩٩٢ ، مستوى لجنتها الفرعية المعنية ببرامج السواتل الصغيرة الى مستوى اللجنة . وأنشئت في نفس الوقت تحت رعاية اللجنة لجنة فرعية جديدة معنية بالسواتل الصغيرة من أجل الدول النامية . وسوف تعمل هذه اللجنة باعتبارها جهة وصل مع لجنة استخدام الفضاء الخارجي في الأغراض السلمية والجامعة الدولية للفضاء والاتحاد الدولي للملاحة الفلكية ولا سيما مع لجنة الاتصال بالمنظمات الدولية والدول النامية .

٥٠ - وتتمثل الأهداف الطويلة الأجل للجنة الفرعية الجديدة في تعزيز استخدام السواتل الصغيرة لصالح البلدان النامية . ويجري تقييم لهذه الفوائد على أساس اقليمي ابتداء من الحالة في أمريكا اللاتينية . ويعد كل تقييم خلال حلقة عمل تنظمها اللجنة الفرعية مع ممثلي البلدان المهتمة بهذا الموضوع . وسوف تنشر التقارير الناجمة عن ذلك وسوف تستخدم كأساس للعمل المقبل . وقد عقدت حلقة العمل الاقليمية الأولى في سان خوسيه دوس كامبوس بالبرازيل من ٢٠ الى ٢٣ حزيران/يونيه ١٩٩٤ بناء على دعوة من المعهد الوطني البرازيلي لبحوث الفضاء .

٥١ - ولا يعتبر أن هناك شكا في النجاح الذي ستحققه السواتل الصغيرة والسواتل الصغيرة للغاية ، بيد أنه يلزم قبل تحقيق الامكانيات الكاملة لهذه التكنولوجيات الناشئة اعادة التفكير جذريا في طريقة تحديد البعثات وتنفيذها وتمويلها وتشغيلها . وينبغي زيادة استطلاع الدور المتغير للتعاون الدولي لهذا الغرض . ونظرا لتنوع طبيعة التطبيقات والأجهزة فان من غير المحتمل أن يلبي احتياجاتها تصميم محمل ساتل صغير عادي لكن يمكن أن يؤدي تبادل أكثف للخبرة فيما يتعلق بتصميمات مختلفة في النهاية الى نوع من التنميط . كما أن القدرة على تكييف المعدات الموجودة بيسر وبتكاليف قليلة ستكون أيضا رصيدا اقتصاديا قيما لكل من الصانع والمستعمل .

٥٢ - من الصعوبات الرئيسية التي تعترض سبيل نشر استخدام تكنولوجيا السواتل الصغيرة من أجل البلدان النامية أن البلدان التي لها برامج فضائية قائمة لا تدرك مدى المشاكل الموجودة في البلدان النامية ، وأن هناك افتقارا الى العاملين المحليين المدربين تدريبا كافيا . ومن المفيد جدا في هذا الصدد أن تولى لجنة استخدام الفضاء الخارجي في الأغراض السلمية مزيدا من الاهتمام لهذه المسألة . ولذا فان من المهم أن الموضوع الذي حدد لكي توليه اللجنة الفرعية العالمية والتقنية اهتماما خاصا في دورتها الثالثة والثلاثين هو "استخدام السواتل الصغيرة والسواتل الصغيرة للغاية للتوسع في الأنشطة المنخفضة التكلفة ، مع مراعاة الاحتياجات الخاصة للبلدان النامية" .

٥٣ - وعلى أساس نتائج مداولات اللجنة حول هذا الموضوع الخاص فضلا عن التوصيات الواردة في هذا التقرير ، قد تقترح اللجنة سبلا ووسائل لضمان احراز تقدم كبير في التعاون الدولي في هذا الميدان المتنامي بسرعة . على سبيل المثال فانها قد توصي بتكريس واحد أو أكثر من الأنشطة التعليمية لبرنامج الأمم المتحدة للتطبيقات الفضائية لموضوع السواتل الصغيرة والسواتل الصغيرة للغاية .

الحواشي

(١) الوثائق الرسمية للجمعية العامة ، الدورة التاسعة والأربعون ، الملحق رقم ٢٠ (A/49/20) ، الفقرة ٢٩ .

Annex

MICROSATELLITES AND SMALL SATELLITES: CURRENT PROJECTS AND FUTURE PERSPECTIVES FOR INTERNATIONAL COOPERATION

Study by the Secretariat*

CONTENTS

---

*The present study has not been edited.

INTRODUCTION

1. Small satellites have already been used with considerable success by many organizations. Their attraction lies in the promise of low cost and short development time, which is made possible by the use of proven standard equipment and techniques, together with a realistic expectation of performance. In fact, the space age began with the launching of small scientific satellites during the International Geophysical Year in 1958. At the time, this was due to the limited capacity of the first space launchers. After a modest beginning with small, simple, and lightweight satellites, space systems have evolved into large, complex, and expensive space platforms for scientific research and other applications which often require many years of development prior to launch.

2. While such large platforms exist and will continue to exist, there has recently been a growing interest in returning to the use of small satellites, which can be launched within a few years after programme initiation. As a consequence of the evolution of the state-of-the-art of space-related technologies, this class of spacecraft can make significant space capabilities accessible to a wide number of users, from high school and university students to engineers and scientists in every country in the world. In many ways, small satellite projects are ideal for extensive international cooperation.

3. The development and utilization of small satellites does not replace the utilization of large satellites missions, as the goals and issues involved are often different. Small missions can, however, be a complement to large missions. By exploring new methods and techniques, small satellites can be a pioneering tool for new experiments and technologies for future larger missions.

4. Small satellites have several advantages over large satellites and these hold no matter who the user is: more frequent and larger variety of mission opportunities; more rapid expansion of the technical knowledge base; greater involvement of local industry; and greater diversification of potential users. The small scale factor also means that even a country with a modest research budget and little or no experience with space technology can afford it. Small satellites also represent an excellent method for training students, engineers and scientists in different disciplines, including engineering, software development for on board and ground computers and management of sophisticated technical programmes.

5. Recent technological progress in many areas means that small satellite can offer services previously only available from much larger satellites. Fairly sophisticated scientific and technological experiments, as well as application missions, can be flown in space at modest costs. The areas of application include: space physics, astronomy, astrophysics, technology demonstrations, communications experiments, and acquisition of Earth resource data, including disaster information.

I. DEFINITION OF A SMALL SATELLITE

6. The definition of a small satellite varies, but an upper limit of about 400 kg (exceptionally 500 kg) is usually adopted within which there are two main categories: small (or "mini") satellites of about 100-400 kg, and microsatellites which weigh less than 100 kg. A typical "small satellite mission" (including launch) generally costs less than $20 million and most microsatellite projects cost approximately $3 million.

7. In recent years there have been three main advances in materials and design techniques which have made small- and microsatellites feasible. In descending order of impact in the design of space missions, they are:

- Substantial advances in data handling, processing and storage technologies, as well as, in sensors for attitude determination. This has been achieved by a very large scale integration of components which permits the manufacturing of high performance systems with small size, mass and power consumption.

- More experience in space systems design and new engineering tool and design techniques (CAD, CAM, etc.), which have permitted more reliable and economical systems to be designed.

- Advances in power generation and power storage technologies as well as in propulsion technologies. Future advances in these fields are expected in the medium-term through the use of new types of solar energy generators, and chemical batteries.

II. ECONOMIC ASPECTS OF SMALL SATELLITES

8. A central issue in any small satellite mission will be the optimum balance between programme complexity and risk. Small satellites are likely to offer new opportunities for procurement methods. The selected model philosophies are very important to both risk and cost, and as a maximum, a protoflight approach will be acceptable for such programmes. The advantages of small satellites are:

- orbital parameters are optimized to individual instrument requirements;
- augmentation of conventional satellite programmes, such as additional capability, redundancy for critical missions, or replacement of a failed instrument;
- missions with limited lifetime and/or coverage requirements;
- improved responsiveness to the end user (more frequent launch opportunities and increased mission flexibility for individual instruments, plus schedule independence);
- quick reaction/launch-on demand launches using low-cost dedicated vehicles, e. g. crisis monitoring, replacement after an on-orbit failure, or monitoring of unexpected environmental conditions;
- relaxed reliability due to the shorter lifetime or agreed, lower levels of product assurance or lower quality parts as appropriate to lower development costs; and
- reduced satellite design complexity (e.g. simplified interfaces, optimized for instrument requirements), shorter development schedule and suitable test-bed for technique/technology proving.

9. However, superior but still economical alternative approaches might be possible in cases where several flight spacecraft are to be produced (successive launches in intervals, constellations, etc.). In such cases, further potential benefits will be available, such as:

- batch production of components and elements;
- "learning" benefits in properly-phased repeated production;
- optimization of test activities (e.g. batch testing);
- minimize facility occupation times;
- minimize GSE requirements and quantities; and
- minimize of programme duration.

10. In principle, a small satellite bus providing a clean physical interface for payload mounting could equally well carry a single large instrument or a number of smaller ones within the same envelope and resource allocation. Using typical and very approximate figures for small satellite programmes in Europe, a budget of 150 Million Accounting Units (MAU -about $200M) over two years could allow a 400 kg class of spacecraft to be launched each year in a long-term programme. The development time to launch a small satellite would typically be three years and the mission life of such a satellite is roughly 2-3 years.

11. The two most often quoted areas for cost reduction on small satellite programmes are the areas of programme management procedures and product assurance requirements, but technical areas may also offer potential. In the programme management area, measures include limiting the geographical distribution of work in order to minimize formal and effort-intensive interfaces between contractors; co-locating a core team of several contractors covering the system design and specification aspects of each programme; and including

payload specialists, so that interaction and compromise between payload requirements and spacecraft provisions can take place.

12. In the technical area, examples of possible sources of cost reduction include designing the systems to lower reliability targets than usual, the possibility of architectural integration between payload and satellite and across satellite subsystems to permit failure recovery by reconfiguration rather than simple functional redundancy, and electronic solutions to system design instead of mechanical ones wherever possible (e.g. image stabilization).

13. Some of the key design elements for developing a small satellite infrastructure can be summarized as follows:

- Standardization of satellite bus and support services, to reduce high non recurring costs and allow for quantity buys of parts and components;
- Standardization of systems, using "off-the-shelf" systems or subsystems that can be incorporated into a spacecraft design, adding significant capability at little incremental cost;
- Utilization of the latest technology, especially electronics, substantially increasing the useful mass ratio of the satellite;
- Design with satellite autonomy as a key feature, to eliminate the costs of significant ground support, and to minimize ground-to-space contact and command-and-control complexity;
- Apply quality assurance practices consistent with the satellite mission (short duration, relatively low cost, acceptable risk of failure), using cost-effective systems which still meet mission goals;
- Resist the escalation of requirements which will drive the satellite design to ever-increasing levels of complexity and sophistication, forcing the mass, power and cost of an (intended) small system to that of a heavy, complex and expensive satellite; and
- Approach the development from a system perspective, viewing the satellite system as a whole, maintaining a balance of requirements among segments of the system cost, launch, on-orbit operations and required information gathering and transmission.

14. The advantages of small satellite projects usually include: a small development team (usually with one or two contractors); short development cycle (usually only a few years); and the satellite is designed to perform relatively few tasks (usually only one).

III. ORBIT SELECTION FOR SMALL SATELLITES

15. There are three general classes of orbits which may be suitable for small satellites: the Geostationary Earth Orbit (GSO), Highly Elliptical Orbits (HEO) and Low-Earth Orbits (LEO).

16. The GSO is where the satellite appears fixed relative to the ground, thus allowing continuous visibility and therefore simplifying the ground segment and operational requirements. However, because of the large space-to-ground distance involved, the data rates would be small, or larger ground antennas and higher electrical power on board the spacecraft will be required. This orbit is usually reached from a standard Geostationary Transfer Orbit (GTO) provided by a large launch vehicle. The circularization of the orbit from the GTO to GSO will require an apogee propulsion system which would roughly double the mass of the satellite at launch. Small launchers will not usually offer enough performance for such missions.

17. The use of a GTO itself is an interesting derivative which could benefit from frequent piggyback launch opportunities, but avoid the complexity and extra costs associated with the apogee propulsion system.

18. Small satellites may by put into HEOs such as orbits inclined at 63.4 degrees. Such orbits are particularly attractive, because the plane is unaffected by the flattening of the Earth, thus it remains

practically fixed in a geocentric inertial reference frame. Certain launchers (e.g. Russian Molniya launcher) are able to deliver satellites into HEO orbits, thus simplifying or obviating the need for an on board propulsion system. High-eccentricity fixed orbits allows minimization of the number of satellites covering certain desired areas which remain visible for long periods of time. This obviously has advantages for telecommunication satellites, but it is not particularly useful for remote sensing missions. As for the GSO, this orbit is not very compatible with assumptions of low mass and low-cost satellites.

19. LEO is generally preferred for small satellite missions. Small launch vehicles can be used, offering flexibility in the selection of the orbit parameters, or piggyback launches may be available. A low energy on board transmitter is sufficient because of the short distance from the ground, but infrequent and short visibility periods are a drawback which will lead to some ground segment and operational complexity. One should also distinguish between the near equatorial or low inclination orbits for which the visibility zone will be limited to the topical zone, and the polar and quasi-polar (Sun-synchronous) orbits which allow accessibility to any point on Earth, either for communication (e.g. store and forward) or for remote sensing of the Earth.

IV. POSSIBILITIES FOR LOW COST LAUNCHING OF SMALL SATELLITES

20. The current and future development of small satellites is closely linked to the appearance of new, low-cost launchers (such as the United States Pegasus, Taurus, etc.) and lower cost launch opportunities on existing vehicles (for example Ariane-4 or small canisters on the Space Shuttle). Indeed, the potential availability of cheap launchers has spurred much of the recent surge of interest in small satellites which was initially largely driven by United States defence and global civil communication programmes. Of the major European and United States low-cost launchers, only Pegasus and Taurus are flight-proven. Conestoga is planned for flight in the near future, development of the Italian San Marco Scout (SMS) has not yet started (although its forerunner, the United States Scout, has been operated for many years), and the Ariane-5 derivative programme which should be completed in 1999.

21. In order to maximize their potential, small launcher developers must apply the same innovative, low-cost design approach used on small satellites. Launch costs represent a large fraction of total programme costs (generally over 25 per cent) and satellite mass and size must therefore be constrained to take full advantage of low-cost launch opportunities. Options include:

- Small dedicated launchers;
- Multiple launch of several small satellites, nominally on Ariane-4 or -5 for European missions (e.g. ESA's Cluster scientific satellites);
- Flight opportunities on larger launchers. Arianespace has strongly promoted its vehicles for this purpose, with Ariane-4 offering: ASAP for "piggy-back" microsatellites (200 kg total, up to 6 x 50 kg satellites); ARSENE-type configuration for satellites up to 200 kg; and SDS for satellites in the 400-800 kg range within the short SPELDA adapter).

22. Similar options are provided by other medium or large launchers, for example the United States Atlas Centaur and the Delta-2. However, small satellites launch opportunities are relatively rare, because resources (mass/volume etc.) are limited and mission parameters and schedule are generally dictated by the main user. The design drivers used when evaluating launcher capabilities against satellite requirements are well known. These include: the available accommodation inside the launcher fairing (this is often a greater constraint than payload to orbit mass capability); the suitability of specific launch site locations for the required altitude and inclination; the cost; the need for a launch on demand capability which, if required, has enormous operational impact (typical surveillance missions may have notification requirements of less than one week).

23. A spacecraft owner needs to assess each launch vehicle option with respect to the following considerations prior to making a launch vehicle selection decision. The most important consideration being the spacecraft value, an assessment of the profit potential and the costs associated with its replacement. A second consideration should be the potential launch vehicle's reliability record or flight history. A series of low-cost payloads may be willing to take the risk of a new lower-cost launch vehicle with an unproven record. Once a commitment is made to a particular vehicle, the spacecraft and its payload will typically require some modifications if it is necessary that it be launched on a vehicle different from the one for which they were originally designed.

V. GROUND SUPPORT NEEDED FOR SMALL SATELLITES

24. Requirements for the ground segment of a small satellite system will vary enormously depending on the application area. At one extreme, low data rate sensors with only local or regional coverage on missions with low tracking and command requirements will impose relatively low demands on the ground segment, possibly comprising only 10 per cent or less of total programme costs. More complex data retrieval and processing requirements could result in ground segment costs of up to 50 per cent of total programme costs. Assuming that ground segment costs tend to average 25 per cent of the programme total, it is clearly important to identify potential savings in the ground segment in concert with those of the space segment.

25. Specific features of small satellites which can be exploited in the ground segment to save costs include: "lower" specifications (as increased risk is acceptable); smaller teams, implying fewer interfaces; and less complexity (restricted objectives), fewer communications channels etc.

26. However, in attempting to reduce the ground segment costs, there are limits on simplification because it is still necessary to ensure the achievement of capabilities such as reliable operation, rapid response to critical commands and regular form of data on time and with low loss. The ground segment model which forms the basis for any technical and cost assessments must include not just the provision of the ground stations but also ground communications infrastructure, mission control, etc. Recently there is also a possibility to use very small stations, in some cases transportable, which are available commercially from several United States and European suppliers. Commercial providers of remote sensing data are likely to press for the adoption of such approaches in attempts to reduce the cost of distributing and processing the data.

27. An important factor in effective implementation of any small satellite project is the need to provide low-cost space-to-ground communication system. Most ground stations are designed to ensure that a complex spacecraft will operate over many years and therefore they have redundancy, self-test functions, and sophisticated capability built- in. A small satellite ground station does not need the same level of capability and could be optimized for the low cost satellite mission. Such a ground station is usually composed of satellite command, control, and monitoring systems as systems for reception of payload data signals. The satellite command and monitoring process is called telemetry, tracking and control (TT&C). The telemetry aspect of space-to-ground communications involves the collection, transmission, and reception of satellite configuration and status data that characterizes the satellite's operation. The tracking aspect determines the satellite ephemeris (position and velocity predictions) through distance, velocity, and antenna pointing angle information. The command element generates commands for remote control of the satellite and often the payload it carries.

28. The typical satellite ground station is composed of five principal elements: the antenna subsystem, the command (uplink) subsystem, the telemetry (downlink) subsystem, the monitoring and control subsystem, and the data processing subsystem. The degree of separation between these subsystems is dependent on the system architecture. The capability, complexity, and robustness of a satellite ground station are determined by a system engineering study in which technical and cost issues are compared and an optimized design for

the mission is produced. Therefore, while the basic elements of a station are common, there is a great deal of variation in the actual design based on the tradeoffs made in the system engineering study.

29. In addition, small satellites are likely to be the cause of major changes in ground systems design and operation because of their new cost-performance characteristics. For example, a major consideration is a potentially significant increase in the number of spacecraft to be controlled. This may result in an increase of the number of missions that can be afforded as well as the use of a constellation of spacecraft to meet the requirements of a single mission.

VI. EXAMPLES OF PROJECTS USING SMALL SATELLITES

A. Small satellites for scientific research

30. Space science activities are obviously valuable, and most space-faring nations have begun their involvement in this field with small scientific satellites. A university environment is often an ideal environment for development of space activities and because such projects often require the creation of new laboratories, these facilities are a lasting, beneficial byproduct of such projects. Thus the usual spin-offs of a space programme, the acquisition of technology and development of industrial organization and management methods, will begin to accumulate at the national level as students leave the university and enter local industry.

31. The following are some examples of small scientific satellite programmes that have been successfully developed. Emphasis is placed on recent programmes of countries with small or modest space programmes.

1. Argentina

32. Argentina's first small scientific satellite will be the SAC-B (Scientific Applications Satellite) which is being developed jointly by Argentina's national space agency, Comision Nacional de Actividades Espaciales (CONAE) and the National Aeronautics and Space Administration (NASA) of the United States. The 190 kg satellite should be launched in 1996 by a Pegasus rocket into a 550 km circular orbit with an inclination of 37 degrees. SAC-B will be inertially stabilized and permanently oriented to the Sun. It will monitor energetic X-rays from solar flares and survey the sky with X-ray CCD sensors along an axis perpendicular to the Sun line. Due to the seasonal motion of the Sun relative to the sky, the 3 x 3 degree detector will scan the entire sky during one year. The design life of the satellite is three years.

2. Central Europe

33. Between 1978 and 1991, scientific micro-satellites weighing 15-50 kg were developed for the Magnetosphere-Ionosphere (MAGION) research programme in the former Czechoslovakia. MAGION-1 was launched on 24 October 1978 as a subsatellite of the INTERCOSMOS-18 geophysical satellite and although it was designed for an operation lifetime of three weeks, it remained operational for three years later. MAGION-2 and MAGION-3 were launched into high-inclination low-eccentricity orbits (altitude 500-3,200 km) as a part of the ACTIVE and APEX mother-daughter active space experiment missions launched 28 September 1989 18 December 1991, respectively. The payload of the subsatellites was used as an independent diagnostic package. During periods when no active experiments were switched on, the satellite and subsatellite were used for simultaneous two-point measurements of natural magnetospheric phenomena.

34. Two more sophisticated MAGION-type subsatellites have been designed for the INTERBALL mission which will study physical mechanisms of solar wind energy accumulation in the magnetosphere and dissipation of the energy in the auroral regions during magnetic substorms. The INTERBALL mission consists of two pairs of spacecraft, situated in different orbits: one pair, the Auroral Probe with an apogee

of about 20,000 km; the other one, the Tail Probe, with an apogee of 200,000 km. Both orbits should have perigee heights of about 500 km and inclinations of 65 degrees. Each pair of satellites consists of the main spacecraft of the PROGNOZ series, accompanied by a subsatellite of the MAGION type. The scientific objectives for the subsatellites are to separate time and space variations, to study spatial correlations and fine structures in the ionosphere and magnetosphere. Separation of the subsatellites will be controlled by small thrusters. The INTERBALL subsatellite payload and subsystems have been developed and manufactured through an international cooperative effort involving Austria, the Czech Republic, France, Germany, Poland, Slovakia, Romania and the Russian Federation. The MAGION-4 subsatellite was successfully launched by a Molniya launcher from the Russian cosmodrome at Plesetsk on 3 August 1995, as part of the INTERBALL-tail mission and MAGION-5 is currently scheduled for a 1996 launch.

35. The Central European Satellite for Advanced Research (CESAR) is a spacecraft of about 300 kg that will fly in an orbit with a 400 km perigee, 1,000 km apogee and 70 degree inclination. The scientific mission is related to the study of the magnetosphere, ionosphere and thermosphere (MIT) Earth environment. Ten different experiments, provided by scientists from Austria, Czech Republic, Hungary, Poland and Slovakia will be accommodated on the spacecraft which is funded by the Italian Space Agency, ASI, and designed by Alenia Spazio. This mission is one of the objectives of the cooperation among the countries of the Central European Initiative (CEI).

36. A feasibility study for CESAR has been started and a detailed technical study funded by ASI will be conducted by Alenia Spazio concerning the spacecraft's system engineering. The participating countries will develop the experiments they are responsible for and will collaborate with each other regarding on board accommodation for the experiments.

37. The nominal mission lifetime will be two years which will allow a sufficient period of observation of the complex MIT phenomena. The evolution of the initial orbit will be determined by the natural perturbations since no propulsion capability is provided on the satellite. The once-per-orbit perigee-apogee excursion, combined with the slow procession of the orbital plane with respect to the Sun and the Earth, will provide the payload with complete sampling of the near-Earth environment between 400 and 1000 km and ±70° latitude in all conditions of illumination over lifetime of the mission.

38. The spacecraft should be launched by direct injection into its required orbit by a small launcher (either an improved Scout or Pegasus). Deployment of the solar array and S-band antennas will follow separation. The spacecraft will be attitude stabilized by spinning around a sun-pointing axis with a rate of 4 rpm. The spin rate will provide the experiments with a fast scan and sampling of the environment surrounding the spacecraft. Boom mounted experiments will be deployed after attitude acquisition. About one month of spacecraft commissioning and experiment calibration will follow. After the nominal operation of the satellite has been certified, the science mission will be carried out for the following two years.

39. The present configuration foresees a mass budget with about 151 kg of service module and 95 kg of payload module for an operative launch configuration mass of 246 kg. A mass margin of 20 per cent is accounted for in the next phase to take into account increases that will surface during the development process. The spacecraft is expected to be completed before the end of 1997 for a launch at the beginning of 1998. CESAR will be the first spacecraft of a series that will also included a second spacecraft currently in preparation, the Joint Ultra Violet Night Sky Observer (JUNO) a UV astronomy satellite being developed in cooperation with NASA. A definition phase study for JUNO is underway.

3. Finland

40. Finnish space industry and research institutions have gathered experience in satellite payloads and instrumentation through their associate membership in the European Space Agency, and have long been active in remote sensing and other space related disciplines. Because Finland does not have experience in satellite

bus development, conducting a small satellite development programme represents a technological leap for the Finnish space industry. The experience gained through such a programme could later be used in bigger satellite programmes. To initiate a study of a Finnish Small Satellite (FS-1), Finnish institutes defined their interests by contacting selected institutes with an unofficial Announcement of Opportunity, and by asking for proposals. After the proposal phase, system design was performed for two alternatives: a scientific satellite and Earth observation satellite. Both satellites would contain a technology demonstration package, in which new electronic components would be tested in the space environment.

41. The payload of the Science Mission (FS-1/SCI) is essentially as proposed by the Finnish Meteorological Institute. The mission is configured to study the fundamental physical processes in the low altitude and high latitude plasma environment of the Earth. The concept includes a polar orbiting satellite (altitude 1,200 km, active lifetime of 1 year) and a large number of ground facilities in the northern polar region. The launch mass of the satellite is 150 kg, including 44 kg of scientific payloads (magnetic field sensors, electrical field sensors, charged particle detectors and component test experiment). The satellite design is a spinning body with electric and magnetic sensor booms and body mounted solar cells. The spin axis should be roughly parallel to the Earth axis.

42. The possible Earth observation mission (FS-1/EO) is optimized to such a single objective, which is not well covered with present Earth observation satellites. Such special objectives are full coverage forest inventory, mapping of sea ice, or a demonstration of a new instrument, for example a 90 GHz radiometer or spectral imager. The satellite design in this case should be a three-axis stabilized body in a polar sun-synchronous orbit (altitude 600 km, active lifetime 2-5 years). The schedule from the start of the phase B (definition) to the launch (probably by a Pegasus launcher) is proposed to be four years.

4. France

43. The French space agency CNES is currently considering the following small scientific satellites:

44. Mission SAMBA: registration of the local fluctuations of 3K radiation from the Big Bang (similar to the United States COBE satellite) and detailed measurement of possible anisotropies. It will use a 55-mm telescope and bolometer, two helium reservoirs for two years of operation, sun-synchronous orbit at 800 km, inclination of 98 degrees, all sky survey except polar regions. The expected mass of the satellite is 120 kg, and planned electrical consumption is 180 W.

45. Mission COROT: astroseismology, new data on the convection and internal rotation of stars by long-term measurement of stellar oscillations. It will study three stars of the F or G type, 4-6 magnitude for 18 months. Planned instrumentation will include a telescope and photomultiplier with a 2 degree field of view, capable of registering light oscillations in a frequency range of 1000 - 5000 μHz with relative accuracy of 2.5 ppm. The mass of the satellite is expected to be about 50 kg, and planned electrical consumption is about 45 W.

46. Mission IBIZA: registration of the plasma accelerated in the geomagnetic auroral regions, interaction of ionized particles with the Earth ionosphere and magnetosphere, creation of electromagnetic disturbances. Two satellites will be launched, both for two years, (similar to the MAGION and CLUSTER programmes). The preliminary mass estimate is 70 kg and power consumption is projected to be 80 W.

47. QUICK-STEP: verification of the equivalence of the inertial and gravitational mass (theory of relativity) with relative precision of 10^{-17}. Instrumentation is based on the measurement of displacement of two masses and will require a liquid helium cryostat. Expected mass is about 400 kg, and planned electrical consumption is 120 W.

5. *Germany*

48. On 3 February 1994, the University of Bremen's small satellite, BREMSAT, was carried into orbit by the United States Space Shuttle Discovery. The 63 kg spacecraft waited six days in its Get Away Special (GAS) container before it was deployed into its initial 350 km circular orbit. Its 57 degree orbital inclination was chosen to enable its operation from the ground station at Bremen's drop tower. The satellite was designed, developed and tested by a private company under contract from the German Space Agency, DARA, during a three year period. The satellite carried six experiments with different scientific objectives, including heat conductivity under microgravity, micrometeorite and dust particle distribution, atmospheric atomic oxygen mapping and re-entry pressures and temperatures. The satellite functioned until its in-orbit decay on 12 February 1995.

6. *India*

49. In the process of the development of its indigenous launching capacity, India prepared a series of small technology development and scientific satellites called Rohini (RS) and Stretched Rohini Scientific Satellite (SROSS) series. The RS satellites were launched between 1980 and 1983 and carried a landmark sensor payload including a solid state camera. More than 2,500 frames in both visible and infrared bands for identification of landmarks and altitude and orbit refinement were obtained. The orbital mass of the RS satellites was about 42 kg.

50. The SROSS satellites were primarily designed for conducting experiments in space sciences, space technology and applications. The mass is around 150 kg and their modular design can accommodate a variety of payloads in the range of 15-35 kg. The design also allows the spacecraft to be operated either in the three-axis stabilized mode or in the spin stabilized mode. The spacecraft is octagonal prism shaped with both body-mounted and deployable solar panels on all sides. The structure is made of a special aluminum alloy with honeycomb construction for the decks.

51. The SROSS-C and SROSS-C2 satellites were launched on 20 May 1992 and 4 May 1994, respectively. They both carried two scientific payloads. The first is the Retarding Potential Analyzer, consisting of two planar detectors to measure plasma parameters and to investigate energetic structure of the equatorial ionosphere. The Gamma Ray Burst Experiment consists of two scintillation detectors to study celestial gamma-ray bursts in the energy range of 20 keV to 3000 keV.

7. *Spain*

52. The National Institute of Aerospace Technology of Spain (INTA), located in Torrejón de Ardoz, Madrid, has been entrusted by the Spanish government with the direction of a research project for the development of a Spanish space system, called MINISAT. The system will consist of a multipurpose platform (service module), payload module and an associated ground segment. Both the platform and the subsystems comprising it are modular in character. The platform will be capable of receiving, integrating, operating and carrying on-board a payload module by means of standard interfaces. This will permit all the required adaptations for a particular mission to be easily conducted. The platform will be able to carry payloads with masses that vary between 80 and 500 kg. The first of these satellites will be the MINISAT mission carrying the PLM-1 (pay load module).

53. This first mission will be for promotional purposes. From among the different possibilities, three technological experiments have been selected. They comprise the measurement of the background radiation in the extreme ultraviolet range, the experimental construction of a new generation of gamma telescope and studies of the deformation produced in a liquid column under different accelerations within the microgravity range. In accordance with the technological and experimental requirements, the PLM-1 satellite will have an approximate mass of 90 kg and will be injected into LEO at an altitude of 600 km, with an inclination

28.5 degrees. The satellite has a planned lifetime of two years. The detail design phases (C2 and D) of MINISAT development were to be completed in 1995 and satellite launch was planned for 1995/1996 period.

8. Sweden

54. The first Swedish-built satellite was the 283 kg Viking which was launched into low polar orbit in 1986 in a piggyback configuration with France's SPOT remote sensing satellite. The scientific objective of the Viking satellite was to study ionospheric and magnetospheric phenomena at high geomagnetic latitudes in the altitude region up to about two Earth radii. Simultaneous measurements were made of electric and magnetic fields, particle distributions, plasma composition and waves as well as imaging in the ultraviolet of the aurora variations.

55. A more advanced small scientific satellite, called Freja, was launched on 6 October 1992 by a Chinese launcher. This 214 kg satellite is designed for auroral research and other related magnetospheric phenomena. The Freja payload consists of a full complement of high-resolution plasma diagnostic instruments and a fast auroral imager. Scientific experiments were also supplied by Germany, Canada and the United States of America. Due to the high telemetry rate and novel design of the instrumentation, which enables more than an order of magnitude higher temporal/spatial resolution compared to its predecessor, Freja is exploratory in many ways. In order to cut costs, only one satellite was built and the protoflight model was first used for all qualification tests, and then for the actual flight.

56. Satellite data are received at ESA's European Sounding Rocket Launching Range (ESRANGE) in Kiruna and at the Prince Albert Satellite Station in Saskatchewan, Canada. Commands for transmitting data and for switching experiments on and off are executed from ESRANGE. The satellite has a stored-command capability in order to operate over Canada without a real-time command link. Full-scale scientific data operations began in late October 1992. Full-scale operations of Freja were planned for two years. The next planned Swedish scientific satellite is called Odin. It will be devoted to spectroscopic studies at sub-millimetre wavelengths of astronomical objects and processes in the Earth atmosphere. Odin is planned to be a multilateral mission that will be launched in 1997 at the earliest.

57. Because Swedish magnetospheric scientists are very interested in the possibilities of small satellites, a compact satellite platform has been developed which is 10 per cent of the mass of the Freja. This new micro-satellite, called Astrid, is the size of a 50 cm box and has mass of 25 kg in its stowed configuration. It is spin-stabilized with a sun pointing capability and deployable solar panels. The first Astrid was launched on 24 January 1995 from the Plesetsk cosmodrome in the Russian Federation on a Cosmos launcher. It carried experiments from the Swedish Institute for Space Physics in Kiruna for monitoring the distribution of energetic particles in the magnetosphere. The launch of the Astrid-2 microsatellite with magnetospheric experiments from the Royal Institute of Technology in Stockholm is expected to take place in 1996.

9. United States of America

58. The best example of the small satellite programmes in the United States is NASA's Small Explorer Program (SMEX), which provides for frequent flight opportunities for highly focused and relatively inexpensive science missions. Small Explorer spacecraft weigh approximately 250 kg and each mission is expected to cost approximately $50 million for design, development and 30 days of in-orbit operations. The first satellite of this series, the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX) was launched on 3 July 1992. It has been successfully investigating the composition of local interstellar matter and solar material, and the transport of magnetospheric charged particles into the Earth atmosphere. The Submillimeter Wave Astronomy Satellite (SWAS) was scheduled for launch on a Pegasus rocket in 1995 or 1996 period. SWAS will for the first time directly measure the amount of water and molecular oxygen in interstellar clouds, and it will also measure carbon monoxide and atomic carbon which are supposed to be major reservoirs of carbon in these clouds. Another satellite, the Fast Auroral Snapshot Explorer (FAST)

should be launched one month after SWAS to probe the physical processes that produce aurorae in the upper atmosphere at high latitudes.

59. An addition, two missions have recently been selected for design, development and launch by Pegasus launchers in the 1997-1998 timeframe. The Transitional Region and Coronal Explorer (TRACE) will observe the Sun to study the connection between its magnetic fields and the heating of the solar corona. The scientific team for this project will include scientists from the Netherlands, Sweden, the United Kingdom of Great Britain and Northern Ireland and the United States. The second spacecraft, the Wide-Field Infrared Explorer (WIRE), will use a cryogenically cooled telescope and arrays of highly sensitive infrared detectors to study the evolution of galaxies.

B. Small satellites for global communication and data collection

60. Advanced satellites that can handle the high data rates needed for real-time, high-quality video and data communications offer unique advantages, for example:

- Mobility. As compact personal communications become more common, users will expect the same access to telecommunications networks from remote areas;
- To supplement and provide back-up for ground based communications; and
- To collect data from widely dispersed in-situ sensor networks that continuously monitor the natural environment with possible concentration on hazardous areas.

61. The amateur radio community has pioneered the use of small satellites for communications. The first of a series of small "ham radio" satellites, the 4 kg OSCAR-1, was launched in 1961 as a piggyback payload on the Discoverer-36 defence satellite. The subsequent satellites in this series, OSCAR 3-8 had greater masses (15-30 kg) and more sophisticated instrumentation which allowed highly reliable amateur radio experiments to be conducted. While the satellites of this type had been initially launched into LEO, recent systems use HEOs or GTOs and plans are even being developed for some GSO positions.

62. Probably the most experienced research unit in the field of microsatellites is the Spacecraft Engineering Research Unit (UOSAT) at the University of Surrey, United Kingdom. Since 1981, UOSAT and, more recently, the Surrey Satellite Technology Ltd. (SSTL) team, have logged over 25 orbit-years of microsatellite operations. There were a total of 10 UOSAT satellites launched between in 1981 and 1993. The operational microsatellite S-80/T is based upon the UOSAT platform and was launched in August 1992 with a mission objective to explore communication possibilities of the VHF WARC-92 bands allocated to non-geostationary satellite systems. The initial mission objective has been successfully achieved and S-80/T completed its first operational year in October 1993 while continuing its flawless functioning. Amateur satellites of the UOSAT series are capable of transmitting images of the Earth's surface as well as meteorological data.

63. The latest additions to the UOSAT family are POSAT-1, HEALTHSAT-2 and KITSAT 2 which were launched together in September 1993 aboard Ariane V-59 along with the SPOT-3 commercial remote sensing satellite. POSAT is the result of a close cooperation between SSTL and a consortium of Portuguese industry. POSAT carries a range of communications, small scale space science, technology demonstration and Earth observation payloads, which, together with an enhanced bus system, make it one of the most sophisticated of the latest generation of microsatellites. KITSAT-2 was built in the Republic of Korea by SSTL-trained engineers. Its platform retains many similarities with the S80/T and KITSAT-1 (launched in August 1992) while some payloads have been developed by Korean engineers. Similarly, the newest SSTL microsatellite FASAT-ALFA, launched on 31 August 1995, was intended to be the first Chilean satellite. It carries 300 Mbytes of SRAM, an Earth imaging camera (with 80 m resolution), an ozone camera and four radiometers for studying the ozone hole, digital store and forward communications using advanced on board data processing and a 3-axis stabilization reaction wheel system. Unfortunately, it has not separated from the main SICH satellite.

64. Part of the reason for UOSAT's success is the remarkably short project time scale and comparatively low project costs that have been achieved. A UOSAT microsatellite mission can be completed within 12 months from contract initiation to in-orbit delivery, enabling a rapid response to the customer's requirement. Time scales are kept short and costs low by the adoption of small-team techniques and a high degree of modularization within the satellite bus and experiments. Technologically, UOSAT has prospered from increasingly widespread availability of low power CMOS processors and memory. While UOSAT was launched with a generous (by 1981 standards) 128k bytes of memory and two on board computers, the latest UOSAT class microsatellites may contain as many as ten computers with up to 48 M bytes of memory. With the exception of the S80/T microsatellite (which operates in a 1,300 km, 66 degree inclined orbit), all UOSAT spacecraft have been approximately 800 km sun synchronous orbits (inclination of approximately 98 degrees). The relatively low radiation dosage, below the Van Allen belts, has allowed the designers to take unconventional approach of using conventional computers and other essentially "off-the-shelf" terrestrial hardware.

65. The use of small satellites for communications is a very complex question and is discussed in detail in separate studies (e.g. A/AC.105/536 "Applications of space technology for remote and rural communications and broadcasting", and A/AC.105/564 "Use of low Earth orbit satellites for voice communications"). For the present study, emerging systems of data collection and distribution by small satellites are worth mentioning.

66. On 9 February 1993, the first Brazilian satellite, SCD-1, was launched in its 25 degree inclination orbit at 750 km altitude by a United States Pegasus launcher. The SCD-1 satellite, designed and built by the Brazilian National Institute for Space Research (INPE) is a small spin stabilized satellite dedicated to the collection and distribution of environmental data acquired and emitted by data collecting platforms distributed over Brazilian territory. Since its launching, the SCD-1 has been performing excellently. A second satellite (SCD-2), very similar to the first one, is now in the final integration stage, to be launched in early 1996.

67. To continue its space programme, INPE is now developing the SCD-3 satellite. It is a small, 200 kg three-axis stabilized satellite that will be injected into a 750 km high equatorial orbit. The mission of the SCD-3 is divided in two parts: environmental data collection and in-orbit testing of a LEO communications system, the ECO-8, also being developed in Brazil. The SCD-3 data collection payload is similar to that of its predecessors but will offer an improved service due to its Earth-pointing orientation and the inclusion of an additional UHF transmitter which allows DCP users to receive the data directly from the satellite by means of a small receiving station coupled to a personal computer. The SCD-3 communications experiment consists of an L/S-band transponder that permits voice communication between small portable terminals through a gateway station. The terminals access the satellite through CDMA and the Alcantara Earth station in northeastern Brazil is used as the gateway.

68. An Italian data collection satellite series is called the Telespazio Micro Satellite (TEMISAT). The first satellite was launched by a Russian Tsiklon launcher from Plesetsk Cosmodrome on 31 August 1993 along with a Meteor-2 satellite. The satellite is orbiting the Earth at 950 km altitude with an inclination of 82.5 degrees, and an orbital eccentricity less than 0.0001. A second unit (Temisat-2) was manufactured together with the first one; it is actually stored on the ground and could be launched to increase the in-orbit service capacity. These are professional microsatellites which, for the first time, adopt for commercial application a low cost satellite-based TDMA/SCPC access scheme. The service offered will be dedicated to data collection and distribution for autonomous networks.

C. Small satellites for remote sensing and environmental observations

69. Remote sensing camera systems can view the Earth and can be used to gather both weather and land data that can help to identify a country's resources and provide early warning of natural disasters. Such systems can also be used to monitor borders, evaluate crops and predict their yield, and improve mapping accuracy. Small satellites are ideal for environmental studies, monitoring biological reservoirs, rain forests,

marine habitats and the progress of the mass destruction of living species and renewable natural resources. They can also be used to provide countrywide surveillance of illegal activities, including those in inaccessible land and ocean areas.

70. Applied to Earth observation missions, small satellites can be utilized independently to fulfil the function of specific payload instruments or several can be flown in a constellation to replace or augment the functions of a larger multi-instrumented satellite. It is clearly not the case of small satellites entirely replacing such large platforms, where considerations such as "economy of scale" and synergy of measurements offer both financial and scientific benefits. Additionally, large satellites are essential where specific instruments must be large enough to achieve their mission objectives, with high power and very high data rates (e.g. depending on the radar antenna size, or optical performance on aperture and focal length).

71. Potentially suitable Earth observation missions for small satellites include: global ocean sampling (by a constellation of satellites); geophysical sampling (by a single satellite in polar orbit); ocean and coastal zone colour monitoring; single instrument payload in support of larger missions, commercial mapping and land surveys; crisis/disaster monitoring (e.g. floods, forrest fires, oil spills), launched on demand or into a constellation; and vegetation monitoring for agriculture and forestry.

72. Japan's recurrent orbit Earth observation satellite project is an example of a small satellite that is being used for remote sensing purposes. Japan is an island country which stretches to northeast and southwest like a bow. Approximately 70 per cent of its land mass is mountainous and most of its population is concentrated in coastal areas. Because of its unique geographical properties, it takes 24 and 16 days, respectively, for the SPOT and LANDSAT remote sensing satellites to observe Japan's main islands. However, it can be understood that the urban area is placed upon a belt faced along the Pacific Ocean. This belt could be covered by just one path of a satellite in an orbit with an inclination around 35-40 degrees. By using a recurrent orbit (with a repeating ground track every 15th revolution), the observation frequency of the area is greatly improved. This is the origin of the Domestic Urban Area Observation Satellite (DUOS) concept. The launch vehicle for this project is the J-1, which is under development by NASDA with a first test flight scheduled for 1996. The launch capability of the J-1 is a payload of 500 kg into a circular orbit with an altitude of 500 km and an inclination of 30 degrees.

73. The DUOS satellite system is based on the Optical Intersatellite Communications Engineering Test Satellite (OICETS) which is currently scheduled to be launched by the J-1 in 1998. It will have a three-axis stabilized bus with two panels of solar arrays and batteries. Within the given mass limit, the satellite could carry the Visible and Near Infrared Radiometer (VNIR), a thermal infrared radiometer (TIR) and a SAR system. However, SAR requires large amounts of electric power which exceeds the capacity of DUOS. Therefore, only the VNIR and TIR instruments are available for this domestic area observation system. A swath width of 150 km is generally necessary to cover an urban area. The number of observation bands, spatial resolution and other parameters must be a trade-off inside the range of data rate by X-band transmission. For continuous observation, two satellites should be operated with the local time difference of 12 hours.

74. The long-term goal of the Technical University of Berlin Satellite (TUBSAT) programme is the development of a three-axis stabilized observation platform that can be autonomously oriented to any desired direction with arc minute accuracy. Of primary interest is the remote sensing of the Earth, so that precise stabilization is required both for observation and for a high data transmission rate to permit real time or almost real time reception of the pictures. These goals are being approached in several steps.

75. The first satellite, TUBSAT-A was launched on 17 July 1991 by Ariane V44 as a secondary payload with the first European Resource Satellite. It is a cube with mass of 35 kg and its attitude is not yet controlled, but very accurately determined by a gyro and magnetometer sensors. After more than four years in orbit, TUBSAT is still completely operational. The only degradation has been the loss of 50 per cent of

capacity of the satellite's chemical battery, although this was fully anticipated. The second satellite in this series, TUBSAT-B with a mass of 40 kg was launched on 25 January 1994 by a Russian Tsiklon launcher together with the Meteor-3-7 satellite. It is equipped with special small reaction wheels and augmented CCD-star sensors. The main purpose of the second satellite was to demonstrate that a control system consisting of three reaction wheels and a multipurpose CCD sensor can damp the residual rotation to zero, identify current orientation of the platform and re-direct the orientation to the desired target by real time interaction from the ground. The main experiment was successfully performed a few days after the satellite was launched, proving that it was possible to stabilize the spacecraft with arc minute accuracy at preselected targets. Contact with TUBSAT-B was lost on 5 March 1994 after 39 days of successful operation, probably due to a failure of the telemetry transmitter.

76. Based on the orbital experience of TUBSAT-A and TUBSAT-B, instrumentation of the third spacecraft will also include three fibre optic laser gyros. A preliminary structure of TUBSAT-C has already been manufactured and is used for three-axis air bearing experiments. The final structure will be designed and manufactured once the launch contract is signed, probably with NASA which offers free launch opportunities to universities on its Delta launchers.

77. Some initial experiments with the Earth Imaging System (EIS) instrument package have been conducted on the UOSAT series of microsatellites. An advanced set of EIS equipment is on the POSAT- 1 satellite launched in September 1993 (with a mass of about 50 kg). This system includes two identical CCD sensors which are fitted with different lenses, offering simultaneous wide and narrow angle coverage of the Earth. Each CCD sensor has 568 x 560 active pixels, electronic exposure control and 256 grey scales. The wide-angle camera has a field of view of 1500 x 1050 km and a mean ground resolution of 2 km (typical for weather imaging). The narrow-angle camera with a field of 150 x 100 km and 200 m per pixel resolution is capable of capturing a range of natural and man made terrestrial features such as bridges, fields, large roads, city blocks, etc. The wide-angle camera senses in the near-IR band (810-890 nm) to give good contrast between land, sea, clouds and ice or snow. To aid its ability to resolve objects in the medium range, the narrow-angle camera uses a red filter (610-690 nm) which highlights variations in soil cover, vegetation density, and human structures. The POSAT-1 remote sensing mission is operational on a daily basis and has gathered some 6,000 images (at the beginning of 1995) with a nominal resolution of 200 m but has demonstrated the capability of detecting land features down to 20 m. It also has image processing and data compression systems that have been operational since December 1994. In the near future, increasingly sophisticated image compression software should be implemented to further improve the output.

78. While the POSAT's EIS does not claim to rival images from large and far more expensive platforms such as SPOT or LANDSAT, the detail in the narrow-angle camera data is reasonably high, unarguably demonstrating the future rôle for inexpensive remote sensing microsatellites. Currently, the imagery does not meet all the needs and expectations of the remote sensing community. The next step will be to develop a three-to-four band multispectral imager using high density CCD sensors (1000 x 1000 or 2000 x 2000 pixels). This type of camera, with a resolution of 80-100 m, could produce imagery similar in many ways to that produced by the LANDSAT Multi-Spectral Scanner, but at a tiny fraction of the cost.

D. The use of small satellites for disaster monitoring and mitigation

79. Development and emplacement of forest fire and other wildland fire warning systems on a global scale is important because of the severe environmental, economic, and social consequences of vegetation fires. Every year, 100,000 km^2 of boreal forest, 400,000 km^2 of tropical rain forest and 50,000-100,000 km^2 of savanna are affected by fire. Up to now, fire detection in near real-time has only been accomplished by aircraft systems on a regional scale in France and in the United States. Airborne systems have the advantage of good geometric resolution, cloud cover independence, and a close connection to the fire managers, but the drawback is that they are only capable of covering a small area. For large area fire research (including fire statistics) and monitoring, satellite systems are necessary. Current satellite sensors used for fire research (not

in real-time, but long after the occurrence of fire) are mainly the AVHRR on NOAA and the LANDSAT-TM sensor.

80. The pre-operational Fire Reconnaissance System (FIRES), recently studied in Germany, will demonstrate the feasibility and usefulness of a future operational small satellite system for fire reconnaissance. It is not only anticipated to be of use for pure detection of a fire event in large areas, but also for its ability to locate, assess the extent (in space and time) and type of the fire and provide this information to local authorities on a timely basis. In addition to this primary task, the system should be able to solve secondary problems such as the assessment of vegetation damage, assessment of atmospheric pollution, and the evaluation of the revitalization of burned areas. Furthermore, when the satellite is not over vegetated areas, its sensor system can contribute to other remote sensing tasks related to high temperature detection.

81. The Smart Multi-Sensor System will be optimized to meet the primary objectives of FIRES. In order to provide the necessary fire information within a few minutes, the sensor system must have a substantial capability for on board decision making and autonomous control. The satellite bus will have a mass of 500 kg, including less than 100 kg of instruments and will be injected into a heliosynchronous orbit with an inclination of 99 degrees, at an altitude of 888 km and with an orbital repeat time of one day (14 revolutions per day). The planned launch date is 1998.

82. Another example of the innovative use of small satellite technology is the Small Technology Initiative of NASA. The first two satellites, named Lewis and Clark, will carry more than 30 different technology demonstrations. Lewis will fly three instruments, including a "hyper-spectral imager" having 384 spectral bands (the operational LANDSAT satellite only has seven bands). It is designed to enhance traditional remote sensing applications in agriculture, global environmental monitoring, forestry, land management and industrial planning. Clark will carry four scientific payloads combining a very high 3 m resolution optical imager with stereo-imaging capabilities. This will be used for commercial remote sensing, disaster management and urban planning. The satellites will have a mass of 272 kg and 317 kg respectively, from which about 70 per cent accounts for the scientific payloads (in existing satellites, it is typically 40 per cent). The launch vehicle will most likely be the Pegasus-XL. The Integrated Product Development team, which will manage the project, consists of more than 35 members from the manufacturing company, NASA centres, universities and high schools.

E. Small satellites for national health and health services

83. The need to expand the availability of quality medical care is particularly great in developing countries, where 80 per cent of the population lives in rural areas while the majority of physicians live in the cities, most often in and around the capital. The access of rural inhabitants to adequate health care facilities is often hampered by poor roads and telecommunications. Space technology could facilitate and enhance health care through dissemination of health information to rural areas, collection of health information from rural areas, administration and coordination of the health network, and education of health care personnel.

84. A satellite health network has been proposed for West Africa by an American non-profit agency, Volunteers in Technology Assistance (VITA), using a constellation of small LEO communication satellites to link regional medical centres with village clinics and mobile health teams. Where more economical, two-way radio-telephones would be used to link villages or mobile units to local clinics, which in turn would be linked to the regional centre via satellite. It was estimated that ten microsatellites could be built and launched for about $21 million, while about $30 million would be required for the medical facilities and the earth station network. Such a system could dramatically improve the access of rural people to good medical care. If successful, this experiment will serve as a model for other remote regions.

85. The experience obtained during experiments with the Healthsat project involving the UOSAT-3 (later re-named HEALTHSAT-1), UOSAT-5 and HEALTHSAT-2 microsatellites, will be applicable to future

projects in this field. There are already functioning HEALTHSAT-2 terminals in Eritrea, Ghana and Sudan. The goal is to provide inexpensive digital communications from the United States, Canada and Europe for medical schools, hospitals and medical libraries throughout Africa.

F. The use of small satellites for education and training

86. The recent availability of relatively low cost launch opportunities has made it conceivable for educational institutions to develop, manufacture, test and operate a small satellite. There is always an emphasis on the active participation of the university community (professors, students, postgraduates) which gives them invaluable practical experience with space technology and scientific research.

87. For example, the first Spanish microsatellite, UPM/SAT 1, with a mass of 47 kg, has been designed and manufactured by the Universidad Politécnica de Madrid (UPM). The purpose was to produce a low cost platform with a moderately long operational life capable of future evolution. It was successfully launched on 7 July 1995 as an auxiliary payload of the Ariane-40 rocket carrying the French Helios-1A satellite. The main experiment on the satellite comprises monitoring of the behaviour of a fluid configuration called liquid bridge in microgravity conditions. Developing a moderately complex design in a university environment should allow professors and students to get the experience necessary for future, more complex projects.

88. The Sunset satellite being developed by graduate electronic engineering students at Stellenbosch University in South Africa is planned for launch in early 1996. It is a 50 kg Ariane launcher compatible microsatellite capable of three colour stereo imaging of the Earth. Pictures can be transmitted in real-time or stored on the satellite. The attitude of the satellite can be controlled within 1 milliradian. The communications package includes an S-band downlink, and amateur radio store and forward communications with an audio repeater to stimulate radio interest among school children. Coarse attitude stabilization is provided by gravity gradient and magnetic torque is improved by small reaction wheels during imaging. Continuous altitude sensing is by magnetometers, solar sensors, visible horizon sensors and a star sensor.

89. The Sunset satellite engineering related research by graduate students and academic staff is the most important element of the programme. The total development time for the first microsatellite is expected to be four years, which includes establishing the research unit and design competence in the student group. The development of the first South African microsatellite is being funded by donations from private companies and matching funds from the Foundation for Research Development. The motivation is for the support of research promotion, technology development and the training of technical manpower.

90. The laboratory of Space Technology at the Helsinki University of Technology was founded in 1988 due to an increased need for education in space technology, as Finland had recently become and associate member of ESA. The main area of interest in the laboratory is microwave remote sensing. The first Finnish satellite programme, the Helsinki University of Technology Satellite (HUTSAT) was begun in 1992. The 50 kg HUTSAT is designed for launch as an auxiliary payload of the Ariane (probably around 1998). The scientific mission of HUTSAT is the three-dimensional mapping of charged particle drifts in several spectral regions. The primary goal of the project is to teach satellite technology to undergraduate and postgraduate space technology students. Over 50 students have participated during the first two years of the project. Some of them carried out only short assignments, but many others accomplished a significant amount of work participating at a postgraduate seminar or a special course on small satellite technology. The feasibility study for the HUTSAT project was conducted solely by students during a postgraduate seminar. It was discovered that if the students are given a certain amount of freedom to solve given problems, the results are sometimes extremely innovative and surprising.

91. Similarly, the concept of the Teaching Company Scheme Satellite (TUCSAT) has been developed under a joint project run by Satellites International Limited, Newbury, and the University of Southampton, United Kingdom. It is aimed at promoting closer links between industry and academia. In evaluating the

measurements which can be made from a small satellite it is important to take account of both the requirements of the Earth observation community for specific data collection as well as the feasibility of making the required measurements within the limits of mass, power and control available on a sub-400 kg satellite. It was therefore decided to define a payload envelope for TUCSAT capable of supporting a number of different systems, rather than to optimize the satellite for a single system and design the configuration and structure around that instrument. This allows two options for the implementation of a TUCSAT-based mission.

92. First, a particular instrument could be identified in association with the producer of the instrument, which could include academic, scientific or commercial establishments, and then the entire system could be offered to a potential customer as a sole use or shared source of data from that instrument, for example in the detection of pollution, or for land use monitoring. The second option is that the satellite bus could be offered to an instrument producer as a low cost flight opportunity, either using the baseline TUCSAT bus or a slightly modified version. A preliminary study has shown that TUCSAT could provide a platform for a range of remote sensing instruments up to 80 kg, with a payload volume of 0.3 m^3. The satellite will support payload operations with an advanced on board data handling system, and a three-axis attitude determination and control system.

VII. POSSIBILITIES OF GREATER INTERNATIONAL COOPERATION IN THE FIELD OF SMALL SATELLITES

93. The opportunities for small and medium size countries to enter into space activities at a relevant level have, in the past, been very limited. Over the past decade, however, technological advances in materials and microelectronics, together with experience gained previously, has allowed many significant space missions to be performed with small satellites. In recognition of the importance of this trend for international cooperation in outer space, the International Academy of Astronautics (IAA) at its meeting in August 1992, elevated the status of its subcommittee on small satellite programmes to the status of a full committee. At the same time, a new subcommittee on small satellites for developing nations was created under the auspices of this committee.

94. According to its terms of reference, the subcommittee on small satellites for developing countries will assess the benefits of small satellites for developing nations in the field of education, space science, communications, Earth observation, medical care etc. It will assess how and to what extent small satellites may contribute to the sustainable development of those nations by providing access to advanced technology and management techniques and by fostering international cooperation. The subcommittee is also concerned with the identification of mechanisms for technical as well as for financial support. It will also develop awareness on those matters in both industrialized and developing nations. The subcommittee will prepare and disseminate the relevant information by organizing workshops and by publishing its findings. It will liaise with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the International Space University (ISU) as well as with the International Astronautical Federation (IAF), particularly with its Committee for Liaison with International Organizations and Developing Nations (CLIODN).

95. The long term goals of the subcommittee are to promote the use of small satellites for the benefit of developing countries. An assessment of these benefits is made on a regional basis, starting with the situation in Latin America. Each assessment is to be prepared during a workshop organized by the subcommittee with representatives of interested countries. The resulting reports will be published and serve as a basis for further actions. The first regional workshop was held on 20 to 23 June 1994 in São Jose dos Campos, Brazil, by invitation from INPE. Some of the conclusions and recommendations from the workshop are provided here because they contain ideas that are also applicable to other regions.

96. From the previous studies prepared by the IAA on the subject of small satellites, and from the results of this workshop, it was concluded that small satellite systems offer the following benefits:

- An independent national space programme can be developed within a short period of time and at relatively low cost, thereby allowing quick entry into the space sector. The study and development of space instrumentation, spacecraft components, sounding rocket programmes, individual small satellite programmes, and cooperative small satellite programmes are low cost opportunities to commence space activities.

- Fairly sophisticated scientific and technological experiments can be flown in space at modest costs, including space physics, astronomy, technology demonstrations, communications experiments, and acquisition of Earth resource data, including disaster information.

- Small satellites present an opportunity for training engineers and engineering students in all engineering disciplines, including software development for on board and ground computers, and in the management of sophisticated technical programmes.

- Opportunities are available for national and international cooperation, to acquire advanced technologies and upgrade a nation's technical expertise in new areas.

- Small LEO satellites offer the promise of inexpensive telecommunications services, and opportunities for international cooperation. Such services could include mobile communications for ships, aircraft, land transportation and personal communications.

- Small satellite systems provide the opportunity to invest limited resources to gradually increase a nation's space infrastructure.

97. Beyond those general benefits, the workshop noted some specific benefits and expected returns from the utilization of small satellites in Latin America:

- Improvement of agricultural and animal productivity in medium to large size rural properties due to better weather forecasting, identification of soil characteristics, improvements in communications and transportation.

- Lowering of transportation costs, made possible through the optimization of truck, bus and ship routing and location, with favourable impacts on prices of goods.

- Provision of communications for the basic needs of small rural settlements in remote areas.

- Expansion of availability, and thus lower prices, for better technology for everyday electric and electronic goods and materials, an indirect effect of the industry participation on quality demanding space projects.

- Improvements in natural disaster detection and relief, made possible by systems that integrate scientific, communications and remote sensing satellite networks.

- Educational programmes for populations in remote areas.

- Job creation in the space and ground facilities industries.

98. Finally, in view of the general benefits, and of the expected return to societies, and taking into account some of the difficulties already experienced, the following recommendations are made. Although they were specifically targeted at countries in Latin America, they nevertheless are valid for other regions of the world.

- Governments should take the steps necessary to make the public and the policy-making governmental officials aware of the importance and benefits of a national space programme so that funding for space activities will be included in the national budget on a sustained basis.

- Countries that are, or want to be, involved in a space programme should develop and publish its national policy so that areas of cooperation can be identified.

- Industry should take initiatives and play a more active role in investing in the development of increased national space activity.

- Any sensitive technologies involved in technology transfer should be identified in advance by the countries involved and related barriers overcome.

- Countries should identify and propose mechanisms to improve access to available technologies for scientific applications.

- Regional representatives should participate in seminars, professional society meetings and other similar fora for the exchange of the latest technical data.

- Countries should attempt to find a market for existing national expertise to sell space hardware and software to other countries for their space programmes, using national academic and industrial facilities.

- In order to improve the access to space of developing countries, particularly through easy access and availability of piggyback missions, the international launch community should periodically publish and distribute notice of potential low cost launch opportunities.

VIII. CONCLUSIONS

99. The eventual success of small and micro-satellites is not considered to be in doubt, but before the full potential of these emerging technologies can be realized it will be necessary to radically re-think the way missions are specified, realized, funded and operated. The changing role of international cooperation to this effect should be further explored. Because of the diverse nature of both applications and instruments, their needs are unlikely to be met with a common small satellite bus design, but more intensive exchange of experience with different designs could eventually lead to some kind of standardization. The ability to adapt existing hardware readily and cheaply will also be a valuable economic asset for both manufacturer and user.

100. Among the main difficulties in promoting the use of small satellite technology for developing countries is the fact that the countries with established space programmes frequently do not understand the scope of problems within the developing countries and that there is a lack of adequately trained local personnel. In this context, it would be extremely valuable, if the United Nations Committee on the Peaceful Uses of Outer Space pay more attention to this issue. It is therefore pertinent, that the theme fixed for special attention during the thirty-third session of the Scientific and Technical Subcommittee in February 1996 is "Utilization of micro- and small satellites for the expansion of low cost activities, taking into account the special needs of developing countries".

101. Based on the results of its deliberations about this special theme, as well as on recommendations contained in the present report, the Committee might propose some ways and means of assuring substantial

progress in international cooperation in this rapidly developing field. It might for example recommend, that one or more of the educational activities of the United Nations Programme on Space Applications be devoted to the theme of micro- and small satellites.

List of acronyms

ASAP - Ariane Structure for Auxiliary Payloads
ASI - Italian Space Agency
AVHRR - Advanced Very-High Resolution Radiometer
CAD - Computer Aided Design
CAM - Computer Aided Modelling
CCD - Charged Coupled Device
CDMA - Code Division Multiple Access
CEI - Central European Initiative
CESAR - Central European Satellite for Advanced Research
CLIODN - Committee for Liaison with International Organizations and Developing Nations (of IAA)
CONAE-Comision Nacional de Actividades Espaciales (Argentina)
COSPAR - Committee on Space Research
EIS - Earth Imaging System
DCP - Data Collection Platform
DUOS - Domestic Urban area Observation Satellite
GAS - Get Away Special
GSO - Geostationary Orbit
GTO - Geostationary Transfer Orbit
GSE - Ground Support Equipment
HEO - Highly Elliptical Orbit
HUTSAT - Helsinki University of Technology SATellite
IAA - International Academy of Astronautics
IAF - International Astronautical Federation
INPE - National Institute for Space Research (Brazil)
INTA - National Institute for Aerospace Technology of Spain
ISAS - Institute for Space and Astronautical Sciences of Japan
ISRO - Indian Space Research Organization
JUNO - Joint Ultra Violet Night Sky Observer
LANDSAT-TM - Land (Remote Sensing) Satellite Thematic Mapper
LEO - Low Earth Orbit
MAGION - Magnetosphere and Ionosphere (Czech Subsatellite)
MCC - Mission Control Centre
MIT - Magnetosphere-Ionosphere-Thermosphere Earth Environment
MSTMC - Multipurpose Space Transport Missile Complex (in Russia)
NASDA - National Space Development Agency of Japan
OICETS - Optical Intersatellite Communications Engineering Test Satellite
OSC - Orbital Sciences
PLM - payload module
POSAT - Portuguese Satellite
RS - Rohini Satellite Series
RTS - Remote Tracking System
SAR - Synthetic Aperture Radar
SPARTAN - Shuttle Pointed Autonomous Research Tool for Astronomy
SPELDA - Structure Porteuse Externe pour Lancement Double Ariane
SROSS - Stretched Rohini Scientific Satellite
START - Strategic Arms Reduction Treaty
SCD - Satellite de Coleta de Dados (Brazil)
SSTL - Surrey Satellite Technology Ltd.
TDMA/SCPC - Time-Division Multiple Access/Single-Channel-Per-Carrier
TEMISAT - Telespazio Micro Satellite

TIR - Thermal Infrared Radiometer
TT&C - Telemetry, Tracking and Command
TUBSAT - Technical University of Berlin Satellite
TUCSAT - Teaching Company Scheme Satellite
UHF Ultra High Frequency
UOSAT - University of Surrey Satellite
VNIR - Visible and Near Infrared Radiometer

Selected bibliography

United Nations Publications

International Cooperation in the Peaceful Uses of Outer Space: Activities of Member States, United Nations Document A/AC.105/567, 21 December 1993

Scientific and Technical Presentations to the Scientific and Technical Subcommittee, United Nations Document A/AC.105/546, 18 May 1993

Scientific and Technical Presentations to the Scientific and Technical Subcommittee, United Nations Document A/AC.105/574, 12 May 1994

Other Publications

Forescue, P., Stark J. (Editors), Space Systems Engineering, Wiley Press, 1991

Griffin, M. D., French, J. R.: Space Vehicle Design, AIAA Education Series,
Washington, D. C., 1991

Holdaway, R., Dunford, E., Ground Station Support for Small Scientific Satellites,
COSPAR Paper 1-M.3.03, World Space Congress, Washington, D.C., September 1992

Inexpensive Scientific Satellite Missions,
IAA Position Paper, Acta Astronautice, Vol. 31, p. 145, October 1993

McKenna-Lawlor, S. M.P., Rusznyak, P., Clark, K., Milton, E., Underwood, C., Afonin, V., Instrumentation for a Micro-satellite to be Flown by a Small European Nation to Implement Earth Observations, Paper IAA-94-IAA-11-2.764, 45th Congress of the International Astronautical Federation, Jerusalem, October 1994

Pirard, T., Small is Beatiful, Mini and Microsats Find International Favour,
Spaceflight, Vol. 37, p. 122, April 1995

Small Missions: Exploiting the Opportunities,
Space Policy, November 1994, 10 (4), p. 322-338

Small Satellites for Latin America, Report of a Workshop of the International Academy of Astronautics, São José dos Campos, Brazil, October 1994

Small Satellites Systems and Services.
Proceedings of the International Symposium, 27 June - 1 July 1994, Biarritz, France

The Case for Small Satellites,
IAA Position Paper, Acta Astronautica, Vol. 31, p. 103, October 1993

Wertz, J. R., Larson W. J., Space Mission Analysis and Design, Kluwer Academic Publishers, Dordrecht, 1990