联 合 国

大 会

Distr.
GENERAL

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

和平利用外层空间委员会

微型和小型卫星：现有项目和国际合作的未来前景

秘书处的说明

1. 评价第二次联合国探索及和平利用外层空间会议（82年外空会议）各项建议执行情况全体工作组在其第八届会议(A/AC.105/571，附件二，第17段）中建议，根据在联合国空间应用方案主办的讲习班、研讨会专题讨论会和会议上通过的建议，外层空间事务厅应进行几项空间应用研究。全体工作组确定了几个可能的研究课题，包括微型和小型卫星，现有项目和国际合作的未来前景。

2. 科学和技术小组委员会第三十一届会议通过了全体工作组的报告(A/AC.105/571，第22段)，和平利用外层空间委员会在其第三十七届会议工作报告[1]和大会在其1994年12月9日第49/34号决议中核可了全体工作组报告所载建议。

3. 本研究报告系由秘书处根据全体工作组的要求撰写的。报告只有英文本载于本说明附件。研究报告的目的是概述迅速发展的小型卫星领域，既使是空间方案数量有限或刚起步的国家也应便利地进入这一领域。撰写本研究报告时引用了大量国家和国际来源的资料，来源一览表列入本报告结尾部分文献目录。报告草稿也曾送交外部专家征求意见。下面是研究报告的摘要。

V. 95-58816 H65

研究报告摘要

4.　许多组织已成功地利用了小型卫星。小型卫星吸引人之处在于它所需费用少且研制时间短，之所以如此是因为使用经实践检验的标准设备和技术，同时对其运作的期望切合现实。空间时代是以 1958 年——国际地球物理年——发射小型科学卫星开始的，之所以发射小型卫星是因为最初的空间发射装置能力有限。在经过以小型、简单和轻便卫星为标志的起点甚低的起步之后，空间系统演化到了能进行科学研究及其它应用的大型、复杂和昂贵的空间平台，这种空间平台发射前通常需要多年的研制。

5.　尽管这种大型平台已经存在并将继续存在下去，现在人们却对回过头来使用小型卫星又越来越感兴趣，因为小型卫星在方案启动几年之后即可发射。由于空间技术的发展，此类航天器可为广大的用户提供具有重大的意义的空间能力；这些用户可以是世界各国的大中学生，也可以是工程师和科学家。小型卫星项目在许多方面都对广泛的国际合作至为理想。

6.　小型卫星的开发不会替代大型卫星的开发，因为它们涉及的目标和问题通常不尽相同。但是，小型卫星的飞行却能补充大型卫星的飞行。通过探索新方法和新技术，小型卫星能够成为为今后大型卫星飞行进行探索性实验和技术的工具。

7.　小型卫星较之于大型卫星有几个优势，而不论用户情况如何：飞行机会更频繁且更多样；能更快地扩大技术知识基础；当地工业能更多地参与；潜在用户范围更广。不仅如此，甚至是研究预算甚少并且空间技术经验极少或没有的国家也负担得起参加小型卫星飞行的费用。小型卫星也为培训学生、工程师和不同学科的科学家提供极好的机会；这些学科包括工程、机载及地面计算机软件开发和尖端技术方案管理。

8.　许多领域近来的技术进步意味着小型卫星能够提供以前只能由大得多的卫星提供的服务。可以以较低的费用在太空进行相当尖端的科学和技术实验及应用飞行。应用领域包括：空间物理、天文学、天文物理、技术示范、通信实验以及获取地球资源数据，包括灾害信息。

9.　对小型卫星下的定义不尽相同，但通常将上限定为约 400 公斤（在例外情况下为 500 公斤），其中有两大类：小型卫星，重约 100 至 400 公斤；微型卫星，重量不足 100 公斤。一次典型的“小型卫星飞行”，包括发射，通常耗资不到 2,000 万美元，大多数微型卫星项目耗资约 300 万美元。

10. 任何小型卫星飞行的核心问题都是方案的复杂程度与风险之间取得最佳平衡。小型卫星可能提供更多的新获取方法。无论从风险还是从费用的角度来看，选定模型的想法都至为重要；对此类方案而言，甚至采取原型卫星飞行的做法亦是可取的。小型卫星的优势如下:

(a) 轨道参数达到能符合任一设备要求的最佳值;

(b) 增强常规卫星方案，如附加能力、关键飞行配有备用装置，或替换失灵设备;

(c) 可进行飞行寿命和/(或)覆盖面有限的飞行;

(d) 提高满足最终用户要求的能力（发射更频、各个仪器设备飞行灵活性增强，以及飞行日程安排的自主性）；

(e) 反应迅速，使用低成本专用装置一经要求立即发射（如监测危机、出现在轨故障后加以替换、或监测突发环境情况）；

(f) 由于它的寿命较短或由于对应于较低的开发费用，其产品保险系数较低，或零部件质量稍差，因而可靠性标准放宽;

(g) 卫星设计的复杂程度降低（如为最大限度地满足设备要求而简化了对接），开发周期缩短以及适于验证技术和（或）工艺。

11. 适合小型卫星的轨道通常有三类：地球静止轨道、超偏心轨道和低地球轨道。

12. 在地球静止轨道上，卫星相对于地球看起来是固定的，因此就可进行连续观察，并简化了地面部分及操作要求。但是，由于涉及的空间至地面的距离很远，数据速率很低，或者就需要更大的地面天线和航天器上更高的电能。通常是从一个由大型运载火箭提供的标准地球静止转移轨道上进入这一轨道。

13. 使用地球静止转移轨道令人很感兴趣，因为它可以利用经常出现的搭载发射机会，而免去远地点推进系统涉及的复杂性和额外费用。

14. 对于小型卫星飞行来说，低地球轨道通常更合适些。可以使用小型运载火箭，这为选择轨道参数提供了灵活性；也可使用搭载发射。由于距离地面较近，卫星上使用一个小功率发射机就足矣，但是观测不频及时间较短是其缺陷，这导致某些地面部分和操作方面的难度。应区分近赤道轨道或低倾角轨道与极轨道和类极（太阳同步）轨道，前者的观察区仅限于热带地区，而后者无论是出于通信目的（例如存储和转发）或地球遥感目的，均可覆盖地球上的任何地方。

15. 小型卫星现在以及今后的开发是与新的低成本发射装置(pegasus 、Taurus ， 等)和现有运载火箭上的低成本发射机遇（如航天飞机上的 Ariane – 4 或小型发射器）的出现紧密相联的。由于有可能出现廉价的发射装置，这使得近来人们对小型卫星的兴趣大增，而这一兴趣最初主要是由美利坚合众国的防务和全球民用通信方案引起的。在欧洲国家和美国的主要低成本发射装置中，只有 Pegasus 和 Taurus 是已经飞行验证的。 Conestoga 计划于近期飞行，意大利的 San Marco Scout 的研制尚未开始(尽管其前身，美国 Scout 已运转多年了），而 Ariane – 5 型的派生方案将于 1999 年完成。

16. 为了最大限度地发挥其潜力，小型发射装置的研制人员应运用与小型卫星上使用的相同的具有创新性、低成本的设计方法。发射费用占总费用的一大部分（通常在 25%以上），因此应控制卫星的质量和大小，以充分利用低成本发射机会。可有以下选择:

(a) 使用小型专用发射装置;

(b) 一次发射多个小型卫星，欧洲的飞行任务都在 Ariane – 4 型和 5 型上顺利进行（如欧洲航天局的集群科学卫星）;

(c) 利用较大发射装置的发射机会(阿丽亚娜航天公司已为此目的大力推广其运载火箭，可提供 Ariane – 4 型: 适合于搭载微型卫星 Ariane 辅助有效载荷结构(ASAP)（最多可有 6 个 50 公斤重的卫星（总重量为 300 公斤））; 适于最高可达 200 公斤重的卫星的 Ariane 无线电业余卫星空间教育(ARSENE)型结构; 以及 SPELDA 专用卫星(SDS)，适合于装在短型阿丽亚娜双体发射外部承载结构(SPELDA)接合器内重 400 至 800 公斤的卫星。

17. 其它中型或大型发射装置，如美国的 Atlas Centaur 和 Delta – 2，可提供类似的选择。

18. 小型卫星系统地面部分的要求通常视应用领域有极大的不同。一方面，在跟踪和指令要求不高的飞行任务中仅仅覆盖当地或区域的低数据数率传感器对地面部分的要求相对较低，后者大约仅占或不到总方案费用的 10%。而更为复杂的数据检索和处理要求则会使地面部分费用占总方案费用的近 50%。假设地面部分费用通常平均占总方案费用的 25%，很显然必须针对空间部分确定地面部分有可能节省的开支。

19. 在努力降低地面部分费用的时候，也不可无限度地简化操作，用为仍需确保实现某些能力，如可靠的运作，对关键指令的迅速反应和准时高效地定期提供数据，地面部分模式构成任何技术和费用评估的基础，它不仅应包括

地面站，而且包括地面通信基础设施，飞行任务控制等。欧洲国家和美国的一些供应商已经提供供商业用的非常小的、有时甚至是可移动的地面站。出售遥感数据者有可能为降低数据分配和处理费用而要求采用上述作法。

20. 空间科学活动显然极有价值，大多数从事空间活动的国家都已开始借助小型科学卫星济身这一领域。大学通常是发展空间活动的理想环境，并且，由于此类项目通常要求创建新的实验室，这些设施成了项目长期、有益的副产品。因此，随着学生们走出大学进入当地工业界，空间方案通常的副产品，即获得技术。建立工业组织和开发管理方法，就开始在国家一级积累起来。

21. 阿根廷的第一个小型科学卫星将是科学应用卫星(SAC-B)，该卫星现正由其国家航天机构，国家空间活动委员会和美国国家航空和航天局共同研制。这颗重 190 公斤的卫星将于 1996 年通过 Pegasus 火箭发射到高度为 550 公里倾角为 37 度的环形轨道上。 SAC-B 卫星将借助惯性稳定下来，并始终朝向太阳。它将监测太阳耀斑的高能 x 射线，并使用 x 射线电荷耦合器件传感器沿与太阳方向垂直的轴线对天空进行测量。

22. 在 1978 至 1991 年期间，为前捷克斯洛伐克的磁层－电离层研究方案研制了重量为 15 至 50 公斤的微型科学卫星(MAGION)。 MAGION － 1 于 1978 年 10 月 24 日发射，作为 INTERCOSMOS － 18 地球物理卫星的子卫星。尽管其设计运行寿命为三周， MAGION － 1 却持续运转了三年。作为分别于 1989 年 9 月 28 日和 1991 年 12 月 18 日进行的 ACTIVE 和阿丽亚娜乘客实验(APEX)母子有源空间飞行任务的一部分， MAGION － 2 和 MAGION － 3 被发射到高倾角低偏心轨道上（高度在 500 至 3,200 公里之间）。 MAGION － 4 子卫星于 1995 年 8 月 3 日作为 INTERBALL －尾巴飞行任务的一部分由闪电号发射装置从俄罗斯联邦的 Plasetsk 发射中心成功地发射。 MAGION － 5 现定于 1996 年发射。

23. 中欧高级研究卫星(CESAR)是一个重约 300 公斤的航天器，它将在一条近地点为 400 公里、远地点为 1,000 公里、倾角为 70 度的轨道上飞行。这一科学飞行任务是要对地球磁层、电离层和热层进行研究。来自奥地利、捷克共和国、匈牙利、波兰和斯洛伐克的科学家准备的 10 个不同的实验将在该航天器上进行。这一航天器是由意大利航天局出资，由 Alenia Spazio 设计的。此次飞行系中欧行动组织各国之间合作的目的之一。

24. 通过其欧空局准成员身份，芬兰的航天工业和研究机构已获得卫星有效载荷和检测仪器方面的经验，并一直活动跃于遥感及其它与空间有关的学科

领域。为了开始一项芬兰小型卫星(FS – 1)研究，芬兰各研究所确定了各自感兴趣的领域，作法是有选择地与一些研究所接触，非正式地通知它们现有的机会并请它们提出建议。在建议期过后，对以下两个选择方案进行系统设计：一个科学卫星和一个地球观测卫星。每个卫星都含有技术示范内容，即在空间环境中测试新的电子元件。

25. 法国国家空间研究中心现正考虑下列小型科学卫星：

(a) SAMBA 飞行：记录大碰撞产生的 3 开辐射的局部振动（类似于美国宇宙本底勘探者卫星）并详细测量可能的各向异性；

(b) COROT 飞行：宇宙地震学，通过对恒星振动进行长期测量获得有关恒星传导和内部旋转的新数据；

(c) IBIZA 飞行：记录在地磁极光区产生的等离子体，电离子与地球电离层和磁层的相互作用以及电磁干扰的产生；

(d) QUICK – STEP：验证惯性质量和引力质量相等（相对论），其相对精确度为 10^{-17} 。

26. 1994 年 2 月 3 日，不莱梅大学的小型卫星 BREMSAT 被美国发现号航天飞机送入轨道。这一重量为 63 公斤的航天器先在航天飞机的分离专用(GAS)装置内放置了 6 天，然后被放入高度为 350 公里的最初环形轨道。这一卫星上要进行 6 个不同科学目的的实验，包括在微引力条件下的导热性、微陨星及灰尘粒子分布、大气层原子氧测绘及重返压力和温度。在 1995 年 2 月 12 日其在轨衰减之前，这颗卫星一直在运转中。

27. 在开发其自身的发射能力时，印度研制出一系列称作罗希尼(Rohini)和延伸型罗希尼科学卫星(SROSS)系列的小型技术开发和科学卫星。罗希尼卫星于 1980 至 1983 年期间发射，并携带包括一台固态摄像机的陆标传感器有效载荷。获得了 2,500 多帧可见光及红外谱带的图象用于识别陆标和高度以及校正轨道罗希尼卫星的轨道质量约 42.2 斤。

28. SROSS-C 和 SROSS – C2 分别于 1992 年 5 月 20 日和 1994 年 5 月 4 日发射。它们各自携带两个科学有效载荷。第一个是制动势能分析器，由两个平面监测器组成，用以测量等离子体参数，并研究赤道电离层的能量结构。第二个是伽马射线脉冲实验，由两个闪烁监测器组成。用以研究在 20 至 3,000 千电子伏特能量范围内的天体伽马射线脉冲。

29. 设在 Torrejón de Ardoz 的西班牙国家航空技术研究所受政府委托负责指导一个名为 MINISAT 的旨在发展西班牙空间系统的研究项目。该系统将

包括一个多功能平台（服务舱）、有效载荷舱和一个相关的地面部分。平台及其作为其组成部分的亚系统都属舱性。使用标准接口，平台能接收、兼容、运作并携带一个有效载荷舱。这将使某一特定飞行所需的所有调整得以容易进行。这一平台将能携带质量在80至500公斤不等的有效载荷。上述的第一颗卫星将是携带一个有效载荷舱(PLM – 1)的MINISAT飞行。

30. 瑞典制造的第一颗卫星是重量为283公斤的Viking；它于1986年与法国遥感卫星、法国地球观测卫星(SPOT)以搭载方式被发射至低极轨道。Viking卫星的科学目标是研究高达约两个地球半径的高空高地磁纬度的电离层和电磁层现象。同时还对电场和磁场、粒子分布。等离子体构成和波以及极光紫外线下成象进行测量。

31. 一个名为Freja的更先进的小型科学卫星由中国制造的发射装置于1992年10月6日发射。这一重量为214公斤的卫星的设计目的是对极光和其它有关的磁层现象进行研究。

32. 瑞典的磁层科学家对小型卫星的潜在价值极感兴趣，他们因此研制出一个质量为Freja的十分之一的小型卫星平台。这一名为Astrid的微型卫星的形状象一个边长约为50x50厘米的盒子，满载时质量为25公斤。它自旋稳定，具有指向太阳的能力和展开式太阳能电池板。第一个Astrid卫星于1995年1月24日从Plesetsk航天中心的Cosmos发射装置上发射。

33. 美国小型卫星方案的最佳例证是美国航天局小探索者(SMEX)方案；该方案为极其专门且费用相对较低的科学飞行任务提供许多飞行机会。每个SMEX航天器重约250公斤，每次飞行中用于设计、开发及30天在轨运作的费用约为5,000 万美元。该系列的第一颗卫星，太阳、异常及磁层粒子探索者号 (SAMPEX)，于1992年7月3日发射。它一直在成功地研究局部星际物质和太阳物质组成以及磁层带电粒子运动至地球大气层的情况。亚毫米波天文卫星(SWAS)将于1995或1996年用Pegasus火箭发射。

34. 在微型卫星领域中经验最丰富的研究部门也许是大不列颠及北爱尔兰联合王国萨里大学的航天器工程研究部。自1981年以来，UOSAT和近来的萨里卫星技术有限公司(SSTL)班子已拥有25个轨道年的微型飞星运作记录。在1981至1993年期间，共发射了10个UOSAT卫星。基于UOSAT平台的仍在运转中的S – 80/T微型卫星是于1992年8月发射的，其飞行目标是探索分配给非地球静止卫星系统的世界无线电行政会议(WARC-92)甚高频波段是否可同于通信。这一最初的飞行目的已成功地实现。S-80/T于

1993 年 10 月结束其第一个运转年，同时继续正确无误地发挥着作用。UOSAT 系列的业余卫星能传递地球表面图象及气象数据。

35. VOSAT 类中的最新卫星是葡萄牙制造的卫星 POSAT-1，HEALTHSAT-2 和 KITSAT-2，它们于 1993 年 9 月和 SPOT-3 商用遥感卫星一起被 Ariane V-59 运载火箭发射。POSAT 是 SSTL 卫星公司和一家葡萄牙企业财团密切合作的产物。KITSAT-2 是由 SSTL 培训的工程师在大韩民国制造的。它的平台与 S-80/T 和 KITSAT-1（于 1992 年 8 月发射）的平台有许多类似之处，某些有效载荷系由大韩民国工程师研制的。

36. 1993 年 2 月 9 日，Pegasus 发射装置发射了第一颗巴西数据收集卫星(SCD-1)，其倾角为 25 度，高度为 750 公里。由巴西国家空间研究所设计并制造的 SCD-1 是一颗小型自旋稳定卫星，专门用于收集并传送由巴西国土上各数据收集平台获得并发出的环境数据。自发射以来，SCD-1 一直运作良好。SCD-2 与 SCD-1 非常类似，现正处于最后组装阶段。它将于 1996 年年初发射。

37. 被称作意大利环境微型卫星(TEMISAT)的意大利数据收集卫星系列中第一颗卫星是由俄罗斯 Tsiklon 发射装置从普列切茨克航天中心与 Meteor-2 卫星一道于 1993 年 8 月 31 日发射的。该卫星在 950 公里高度上，以 82.5 度的倾角和不到 0.0001 的轨道偏心率环绕地球飞行。第二颗卫星(TEMISAT-2)是与第一颗卫星一道制造的；它现正存放在地面，可为增强在轨服务能力而发射。

38. 如将其应用于地球观测飞行，小型卫星可被独立使用，以履行特定有效载荷仪器的功能。几颗卫星可作卫星群飞行，以替代或增强大型多仪器卫星的功能。小型卫星将不会完全取代这种大型平台，因为大型平台带来经济效益和科学效益，如规模经济及测量上的最佳协同效果。除此之外，在需要足够大型的特定仪器以便以高功率及非常高的数据速率（如取决于雷达天线的大小或孔径和焦距的光学性能）实现飞行目标时，大型卫星是必不可少的。

39. 可能适合小型卫星的地球观测飞行包括：全球海洋抽样（由卫星群进行）；地球物理抽样（由极轨道上的单一卫星进行）；海洋和海岸区颜色监测；辅助较大型飞行的单一仪器有效载荷、商业制图和土地勘测；危机和（或）灾害监测（如洪涝、森林火灾、石油泄漏），一经要求即发射或发射至卫星群中；以及为农业及林业进行植被监测。

40. 日本的重复轨道地球观测卫星项目提供了小型卫星正被用于遥感的例

子。通过使用一个重复轨道（每当第 15 次公转时即有一个重复地面轨迹），大大提高对一个地区的观测频率。这即是国内城市地区观测卫星(DUOS)这一设想的起源。

41. DUOS 系统的基础是现计划由 J-1 于 1998 年发射的卫星间光学通信工程试验卫星。该卫星有一个三轴稳定航天器以及两组太阳能电池组和太阳能电池。在额定质量限度内，卫星可携带可见光及近红外辐射计和一个热红外辐射仪。

42. 柏林卫星技术大学(TUBSAT)方案的长期目标是研制一个三轴稳定观测平台，该平台能够以极其精确的弧度自动指向任何需要的方向。主要关心的是地球遥感，因此为了观测以及便利实时或近乎实时图象接收的高数据传输率，需要精确的稳定。现正以几个步骤实现这些目标。

43. 在分别于 1991 年和 1994 年发射的 TUBSAT-A 和 TUBSAT-B 的轨道经验的基础上，第三个航天器的设备中还将包括三台光导纤维激光陀螺仪。现已制造出 TUBSAT-C 的初步结构，并正用于三轴空气承受实验。

44. 最近正在德国研究的运转前火灾侦察系统(FIRES)将证明今后将投入运转的小型火灾侦察卫星系统的可行性及功益。预计它将不仅能用于单纯地面发现大面积地区的火灾，而且还能对火灾定位、评估火灾程度（空间及时间）和类型并及时向地方当局提供这一信息。除了这一首要任务之外，该系统应能解决诸如评估植被受损情况，大气污染以及受灾区的恢复等次要问题。另外，在卫星不在植被区上方时，其传感器系统能有助于完成其它与高温监测有关的遥感任务。

45. 美国的一个名为技术援助志愿人员团的非盈利机构已建议为西非建立卫星保健网络，作法是利用几颗小型低地球轨道通信卫星将区域医疗中心与村诊所和流动医疗队联系起来。如更合算，可用双向无线电－电话将村或流动部门与当地诊所联系起来，后者则通过卫星与一区域中心联系。据估计，使用 2,100 万美元可以制造并发射 10 个微型卫星，而医疗设施和地面站网络则需约 3,000 万美元。这样一个系统能够极大地改善农村居民获得良好医疗服务的机会。这一实验如果取得成功，将成为其它偏远地区的样板。

46. 由于近来可以获得成本相对较低的发射机会，人们可以设想由教育机构来研制、生产、测试并操作小型卫星。人们一直都在强调大学界成员（教授、学生、研究生）应积极参与，这为他们提供在空间技术和科学研究方面宝贵的实践机会。

47. 例如，质量为 47 公斤的西班牙第一颗微型卫星 UPM/SAT 1 是由马德里工业大学设计并制造的。它是一个低成本平台，运转寿命较长，且能在今后进一步发展。它是于 1995 年 7 月 7 日作为携带法国 Helios-1A 卫星的 Ariane-40 火箭的辅助有效载荷发射的。卫星上的主要实验包括监测在微引力条件下一种被称作液体桥的流动构造的行为。在大学环境中开发稍许复杂的设计应能使教授和学生们获得进行更为复杂项目所需的经验。

48. 正由南非 Stellenbosch 大学电子工程专业研究生研制的日落卫星计划于 1996 年年初发射。它是一颗重 50 公斤的微型卫星，可与 Ariane 发射装置兼容，能对地球进行三色立体成象。图象可实时传送或存储在卫星上。卫星的高度可在 1 毫弧度之内控制。其通信装置包括一条 S 波段下行线路，带有音频中继器的无线电业余存储及转发通信装置，以激发小学生对无线电的兴趣。

49. 以往中小国家在相应的水平上涉足空间活动的机会有限。但是，过去十年中在材料和微电子方面的技术进步和获得的经验已使用小型卫星进行许多重大空间飞行成为可能。认识到这一外层空间国际合作趋势的重要性，国际航天学会在其 1992 年 8 月会议上将其小型卫星方案小组委员会的地位提升到了正式委员会的地位。与此同时，在这一委员会的主持下，成立了一个新的发展中国家小型卫星小组委员会。它将作为与和平利用外层空间委员会、国际空间大学和国际宇宙航行联合会联络的机构，特别是与后者的国际组织和发展中国家联络委员会的联系。

50. 这一新的小组委员会的长期目标是为了发展中国家利益而促进对小型卫星的利用。对这些利益的评估是在从拉丁美洲开始的区域基础上作出的。在由小组委员会组织并由有关国家代表参加的讲习班上，分别作出评估。将发表有关评估结果的报告，并在此基础上采取进一步行动。应巴西空间研究所的邀请，第一个区域讲习班于 1994 年 6 月 20 日至 23 日在巴西圣若泽杜斯坎普斯举行。

51. 小型和微型卫星终将成功，这一点无庸置疑；但是，在这些新兴技术的潜力能够被充分发掘之前，必须深刻反思有关飞行的确定、实现、筹资和操作的作法。应进一步探索这方面国际合作作用的转变。由于应用领域和仪器的性质有差异，靠常见的小型卫星航天器设计很难满足需要，但是与不同的设计进行更广泛的经验交流最终会导致某种标准化的出现。如有能力对现有的硬件随时进行低成本的改造，这无论对制造者还是对用户来说都将是宝贵

的经济财富。

52. 在为发展中国家推广使用小型卫星技术中有许多主要难题，其中之一是，现已制订空间方案的国家通常不理解发展中国家内问题的严重程度，同时还缺少受过足够培训的当地人员。在此方面，和平利用外层空间委员会如能更多地注意这一问题，这将极有裨益。因此，科学和技术小组委员会在其第三十三届会议上将特别注意的既定主题定是“在考虑到发展中国家特殊需要的情况下利用微小型卫星，扩大低成本活动”，这一决定甚为贴切。

53. 根据就此特别主题审议的结果，以及本报告中所载各项建议，委员会似拟就确保如何在这一迅速发展领域中国际合作取得重大进展的某些方式方法提出建议。例如，它可建议联合国空间应用方案的一项或多项教育活动应专门涉及微型和小型卫星这一主题。

注

1 《大会正式记录，第四十九届会议，补编第20号》(A/49/20)，第29段。

Annex

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

Study by the Secretariat*

CONTENTS

Pages

*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 role 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