Association for Machines and Mechanisms News Bulletin

Volume 7, No. 2 April 2015

Objectives and Activities

The main objective of AMM is to contribute to mechanical design at all levels starting from academic research to industrial initiatives, thereby enhancing the quality and reliability of indigenous machines. With this in view, AMM organises the International & National Conference on Machines and Mechanisms, iNaCoMM, and the workshops on Industrial Problems on Machines and Mechanisms, IPRoMM regularly.

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Contact Details

Dr. G. Saravana Kumar

Secretary, AMM

Tel: (044) 2257 4736 (O)

Fax: (044) 2257 4732

E-mail: secretary@ammindia.org

Web Site: http://www.ammindia.org

Message from the Editor-in-Chief

With the scorching heat stepping in after the spring season, Volume 7, No. 2, April 2015 issue of the Bulletin of the Association of Machines and Mechanisms (AMM) is being published in this late April.

Dr. R. Ranganath, the Zonal Vice President (South), has taken the main responsibility to bring out this issue of the Bulletin. His group has contributed an interesting article on "Spacecraft Docking Mechanism- A Brief Overview". This article makes a review on the state-of-the-art systems regarding interplanetary exploration for landing on Moon, Mars and the most recent step to land on a Comet. This article is sure to enthuse not only members of the Association of Machines and Mechanisms, but also other readers who take due interest in space missions and related astronomical issues.

The iNaCoMM-2015 and some other events associated with the Association are being organised in the coming months. Interested persons may find the briefs about these events in this issue of the Bulletin similar to previous issues and can decide on sending articles and/or participate in the same.

Dr. G. Sarvana Kumar, the Secretary of the AMM, and other office bearers of AMM have taken due initiative to publish this issue. The Editor-in-Chief gratefully acknowledges the support extended by the office bearers and Editorial Board members.

For bringing out July 2015 issue, AMM members are requested to contribute articles, technical briefs, etc. and send same to the editorial team. Constructive suggestions, comments towards improvement of the Bulletin of the AMM are most welcome.

Prof. Santanu Das

Editor–in–Chief

About the Association of Machines and Mechanisms (AMM)

The AMM headquarter is currently located at the Department of Engineering Design, IIT Madras. A new set of office bearers have taken charge of the affairs of AMM. AMM invites both individual and corporate membership from Indian academia, research organizations and industry. Membership benefits and other information about AMM are available at www.ammindia.org. The body of Zonal Vice Presidents (ZVPs) is active over the past several years with representations from the four corners of the country. They are playing the role of nodal agencies so as to decentralise the AMM official activities and to organise workshops under the aegis of AMM to popularise the mechanism science in their respective regions. They also form the editorial team of this news bulletin. AMM invites contributory articles from its members and others working in the various fields of mechanisms science for this quarterly news bulletin. Interested people can contact the editorial team.

Office Bearers of the AMM:

Prof. C. Amarnath (President)
Retired Professor,
Department of Mechanical Engineering,
Indian Institute of Technology, Bombay,
Powai, Mumbai 400076, INDIA

Phone: + 91 80 2368 2151
Email: president@ammindia.org

Dr. G. Saravana Kumar (Secretary)
Department of Engineering Design,
Indian Institute of Technology, Madras,
Chennai 600036, INDIA.

Phone: + 91 (44) 2257 4736
Email: secretary@ammindia.org
Web: http://ed.iitm.ac.in/~gsaravana

Prof. Ashitava Ghosal (Vice President)
Department of Mechanical Engineering,
Indian Institute of Science,
Bangalore 560 012, INDIA.

Phone: +91 80 2293 2956
Email: vicepresident@ammindia.org
Web:
http://www.mecheng.iisc.ernet.in/~asitava

Dr. Palaniappan Ramu (Treasurer)
Department of Engineering Design,
Indian Institute of Technology, Madras,
Chennai 600036, INDIA.

Phone: + 91 (44) 2257 4738
Email: treasurer@ammindia.org
Web: http://ed.iitm.ac.in/~palramu

Editorial Team of the News Bulletin:

Dr. Santanu Das (Editor-in-Chief, News Bulletin)
Professor and Head, Department of Mechanical Engineering
Kalyani Govt. Engineering College, Kalyani- 741235, INDIA

Phone: +91 (33) 2582 1309
Email: sdas.me@gmail.com

Dr. Shankar Sehgal, (Zonal Vice President [ZVP] North)
Assistant Professor,
Mechanical Engineering Department,
Room No. 102, Block 2, U.I.E.T., Sector-25
Panjab University, Chandigarh- 160 014.
INDIA

Phone: +91 95010 24161
E-mail: shankarsehgal@yahoo.com

Dr. R. Ranganath, (ZVP, South)
Spacecraft Mechanisms Group,
ISRO Satellite Centre,
Bangalore-560017, INDIA

Phone: +91 (80) 25082417
Email: rrrr@isac.gov.in

Dr. Ranjit Kumar Barai, (ZVP, East)
Associate Professor,
Control System Laboratory,
Electrical Engineering Department,
Jadavpur University, Kolkata- 700 032,
INDIA

Phone: +91 (33) 24139270
Email: ranjit.k.barai@gmail.com

Dr. Shital S. Chiddarwar (ZVP, West)
Assistant Professor,
Dept of Mechanical Engineering
Visvesvaraya National Institute of Technology, Nagpur, INDIA

Phone: +91 9561050130
Email: shitalsc@mec.vnit.ac.in

Education is basic to the creation of an atmosphere in which human beings can meet one another on a plane of friendship and equality.

--- Maulana Abul Kalam Azad

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IFToMM

International Federation for the Promotion of Mechanism and Machine Science

Mission

To promote research and development in the field of Machines and Mechanisms by theoretical and experimental methods, along with their practical application

Vision

To provide leadership for cooperation and development of modern results in the Mechanism and Machine Sciences by assisting and enhancing international collaboration

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IFToMM, April 2014

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- establish contacts between researchers and engineers;
- initiate and develop bases and procedures for modern problems;
- promote the exchange of information;
- organize national and international symposia, conferences, summer schools, and meetings.

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Joining IFToMM Member Organizations gives the following benefits:

international contacts for potential developments of joint projects;
reduced registration fees for IFToMM supported conferences;
participation and contribution in IFToMM activities and publications;
flow of information on IFToMM activities.

You are kindly invited to join IFToMM and its activities.

Spacecraft Docking Mechanism- A Brief Overview

Anoop Kumar Srivastava[1] and R Ranganath[2]

Spacecraft Mechanisms Group,
Indian Space Research Organisation, Satellite Centre, Bangalore
[1]Email: akrs@isac.gov.in,
[2]Email: rrrr@isac.gov.in

1 Introduction

Present day scenario in space exploration has matured much beyond the aggressive competition among select nations towards proving technical superiority of the early 60s. It now touches each and every aspect of life tending towards finding ways of survivability of humans in space. Giant steps have been taken towards interplanetary exploration from landing on Moon to landing on Mars with the most recent one being landing on a Comet. Time has come when joint collaborations in the field of space exploration is becoming a necessity for realising an alternate habitat to mankind.

Extending space exploration beyond the limits of earth observation could not be done without the development of some key technologies. One of the most crucial among them is the development of spacecraft docking technology. The rendezvous and docking of satellites forms the backbone of several proven services in space exploration like-

i) Building of large structures and laboratories in space; eg: MIR Space Station, International Space Station (ISS)
ii) Servicing of spacecrafts; eg: servicing of Hubble's Telescope
iii) Human interplanetary exploration; eg: Apollo programme for Landing on Moon

Advances in the field of docking were a result of intense technological race between the Russians and Americans. The Russians took the early lead by launching the Sputnik. The Americans in response announced their ambitious plan of landing a man on the moon and bring him back safely to earth. This triggered developmental activities which required a number of mission critical docking and undocking activities during the onward journey to the moon and for the return flight. The early 1960s witnessed tremendous developmental activities and conduct of docking experiments. The first successful docking could be achieved by Gemini VIII on March 16, 1966 with Agena Spacecraft [10]. This was later followed by the successful landing of men on the moon in Apollo 11 mission and their safe return to earth in 1969. This successful mission heralded a new dimension to the human spirit of exploration and a new impetus to space research.

Needless to say, the docking mechanism is one of the critical systems in the success of space docking missions. This paper addresses a brief overview of docking mechanisms in different missions. Table 1 shows in brief the evolution of docking mechanisms from the 60 to till date including that in the near future.

Table 1: Docking mechanism at a glance

Vehicles	Masses	Year	Mechanism
Gemini-Agena	3789kg-3175kg	1966	Index bar-docking cone.
Apollo: Command Service Module(CSM)-Lunar Module(LM)	30332kg- 14696kg	1969	Probe and Drogue
Apollo-Soyuz	16780kg- 6790kg	1975	International Docking Mechanism (androgynous)-APAS75
Soyuz/Progress-ISS	~7000kg- 344378kg	2003-Present	Probe and Drogue
Shuttle-ISS	~80000kg – 344378kg	1998-Present	APAS 75, APAS 89, APAS 95
ATV - ISS docking	Upto 28T	First Flight planned in 2016	International Berthing and Docking Mechanism (IBDM)
ISS docking	Lowest 1183kg	Unity to Zarya 1998 to till date	Common Berthing Mechanism (CBM)
ISS docking	5000 Kg– Chaser and Target (Light) 25T Chaser to 350T Target (Heavy)	Futuristic	NASA Docking System (NDS)
ETS VII: Orihime – Hikoboshi	400kg- 2200kg	1997	Low impact mechanism : Claws and handle bars
Orbital Express: ASTRO-NextSAT)	1088kg- 226kg	2007	Three pronged Starsys docking mechanism
Shenzhou 8 – Tiangong 1 Docking	8082 kg- 8506 kg	2011	APAS -95
Mini AERCAM - ISS	5kg- 344378 kg	Futuristic	Magnetic docking system and ball lock mechanism
Docking concept for pico satellites	1 to 5 kg	Futuristic	Micro cilia arrays (MEMS based)

2 Classification of Docking Mechanisms

The docking mechanisms can be classified based on the impact energies, mode of operation, pressure sealing and modularity in configuration. Figure 1 shows this classification pictorially.

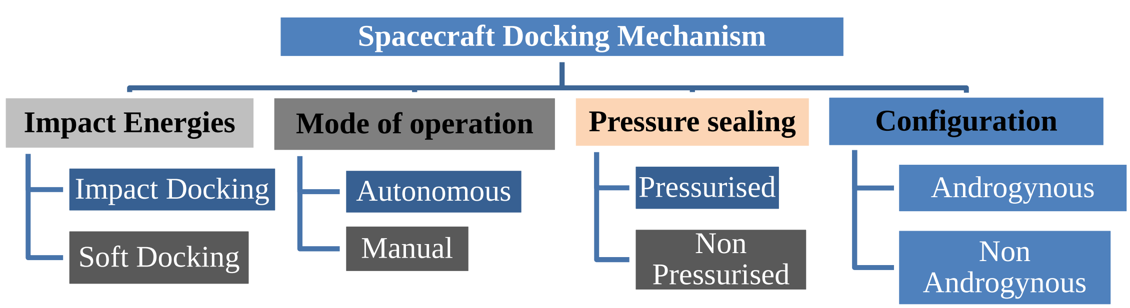


Figure 1. Classification of spacecraft docking mechanism

The figure above gives a very broad classification of the docking mechanisms used for spacecrafts. Details of each are discussed in the subsequent sections

2.1. Impact Energies

For docking between the two spacecrafts to occur a positive relative velocity between the two spacecrafts is a necessity. This results in relative kinetic energies between the two spacecrafts. Docking is the instance when two spacecrafts are joined together in space. At this instance if the relative kinetic energy is absorbed or dissipated to a large extent, then the docking procedure adopted is called as *soft docking or low impact docking.* On the other hand if this energy is made use of for actuating the capture mechanism or in simple terms not attenuated to a large extent then it results in *Impact docking*. Both have their inherent advantages and disadvantages which were used while configuring the systems. Typical examples of Low impact docking are the present Androgynous Peripheral Attachment System (APAS 95) used on ISS-Shuttle and example of impact docking is Apollo docking mechanism. The impact docking is generally preferred when the spacecraft involved in are axi-symmetric and their centre of mass are aligned. The proximity sensors requirements for impact docking are less stringent in comparison to that of soft docking. For large flexible and locally fragile spacecrafts and where the centre of mass of the chaser and target are offset from each other, soft docking is generally preferred.

Impact docking was used by Apollo missions in their probe and drogue type of docking mechanism and also by the Russians. This enables the spacecrafts to be captured without the use of active capture mechanism and the two spacecrafts get captured using the kinetic energy of the spacecrafts. Another important aspect is the docking disturbances which are discussed in subsequent sections.

2.2. Mode of Operation

Docking sequence can be made to be conducted by direct intervention of Astronauts, by ground command or it can also be made autonomous. The autonomous features gain importance when dealing with interplanetary missions. In manual docking sequence, a target and a marker is used for achieving the requisite alignments making use of manual operation of thrusters in pulse mode. For autonomous docking sequence, closed loop operation making use of sensors is performed where corrective actions are taken for every misalignments observed. In this mode even the capture, stabilisation, retraction and rigidisation is performed by onboard autonomous commands.

2.3. Pressure Sealing

Docking mechanism for spacecrafts are used for all purposes including human transfer, material transfer, refuelling and repair services. Instances when shirt sleeve environment for astronauts has to be ensured, in such scenarios pressure sealing has to be achieved across the docking ports. This is done making use of pressurised locking and fastening mechanism which ensures very low leakage of air. However, where only material transfer is required or repair service has to be performed externally in such instance pressure sealing can be avoided. The two docking modules are rigidised in non pressurised state and the activities are performed. Pressure sealing becomes a large overhead on the overall system thus the application of that is always scrutinised and then adopted.

2.4. Configuration

This classification basically deals with the design configuration which is directly based on the development of the type of docking mechanism. Earlier developed docking mechanisms including Apollo and Gemini were centrally placed and along the axis of symmetry. They were of the non androgynous types as they had two different modules for chaser and target spacecrafts. Subsequently, the mounting of docking mechanism on the periphery became popular as their capture and rigidisation elements could be place on the periphery and were simpler in operation in comparison to centrally placed docking mechanism. To increase the reliability of operation, androgyny was adopted so that identical mechanisms are mounted on the chaser and target. This enabled either of them acting as chaser or target.

3 Docking Disturbances

Docking disturbance is a function of docking force and docking time. Disturbance can be in terms of resultant force or resultant torque. The resultant torque is obtained as a product of docking force and perpendicular distance of the application of force to the CG of the spacecraft (d). This would tend to spin the two spacecrafts. Mathematically it can be seen as given below

Docking disturbance = f (docking force, docking time)

Disturbing moment = docking force x distance of CG from the docking port

The docking force is a function of the relative velocities between the two spacecrafts at contact. The docking time is a function of the characteristics of the capture mechanism. If the relative velocities between the two spacecrafts are kept low at contact and time of operations of the capture latches are kept to a minimum (fast acting), the docking disturbances can be reduced.

Large docking disturbance present in impact docking results in considerable burden on the spacecraft control systems. It is preferred to reduce it significantly and this is achieved in soft docking methods.

4 Types of Docking Mechanisms

Since the advent of the docking technologies giant steps have been taken in this field. Latest technologies have matured way beyond from the first Gemini VIII adaptor cone based docking mechanism. Docking mechanism in the initial days was operated using manual commands and the presently fully autonomous docking mechanisms have become operational for unmanned missions. Each type of docking mechanism is configured suiting to the requirements of the approach parameters as defined by the mission. Change in these approach parameters lead to major configuration changes. There have been developments of various kinds of docking mechanisms apart from the ones used by ESA and NASA for ISS. They are used for docking of small satellites. The subsequent article shall deal with the type of docking mechanisms developed and their approach parameters which provide the baseline for the design of the docking mechanism.

4.1. Gemini Docking Mechanism

Gemini docking was performed between Gemini and Agena spacecrafts using a cup and a cone arrangement as shown in figure 1. This was operated manually by the Astronaut on Gemini and docking was achieved between the active Gemini Spacecraft and passive Agena spacecraft.

The V shaped indexing bar is used for the alignment of the spacecrafts. This was a non androgyny non autonomous docking mechanism which did not allow for crew transfer between the two spacecrafts.

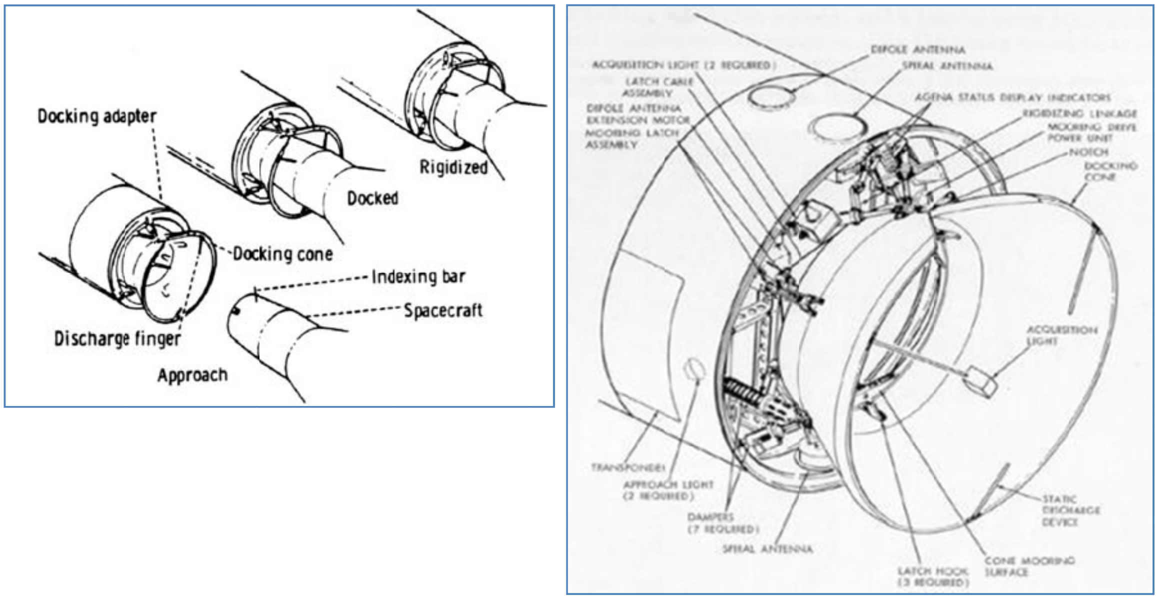


Fig 1: Gemini docking mechanism [11][25]

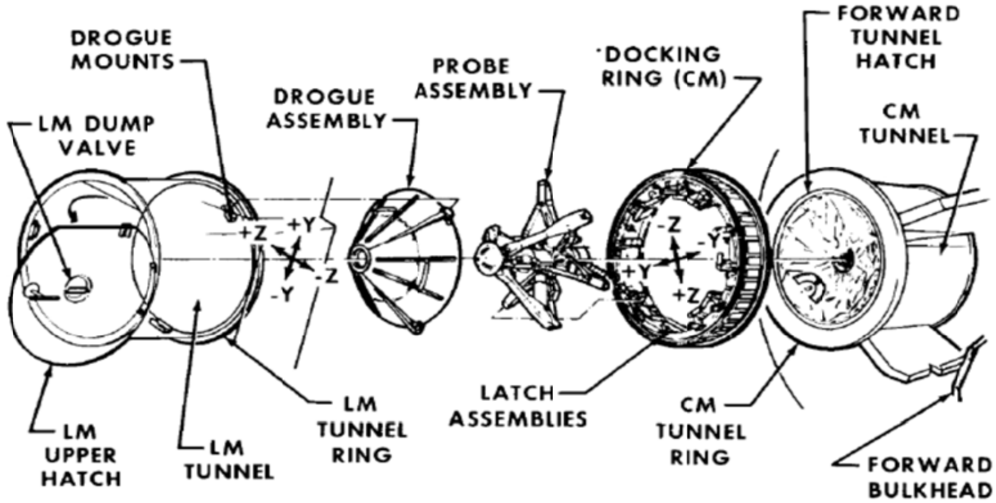
4.2. Apollo Docking Mechanism

The Apollo docking mechanism as shown in figure 2, used the first probe and drogue docking mechanism which was an improvement over the Gemini Agena docking mechanism. It had an extending probe which would perform docking with the drogue present in the chaser spacecraft. This was also a non autonomous docking system wherein the crew would manoeuvre the spacecraft to close proximity and close in for docking in step based docking procedures.

Apollo Approach parameter [8] of the Apollo docking mechanism are given below

Axial (Closing) Velocity	- 0.0305 to 0.305 m/s
Radial (transverse) Velocity	- 0.0 to 0.1524 m/s
Angular velocity	- 0.0 to 1.0 degree/second
Radial Alignment	- 0.0 to 0.3048 m
Angular X axis Alignment	- 0.0 to 10 degrees
Rotational Alignment	- minus 60 degrees (± 10 degrees)

This along with gemini docking system belong to the family of impact docking mechanism where the relative kinetic energy of the spacecrafts is used to actuate the locking mechanism. Details of the mechanism used is available in Reference 13.



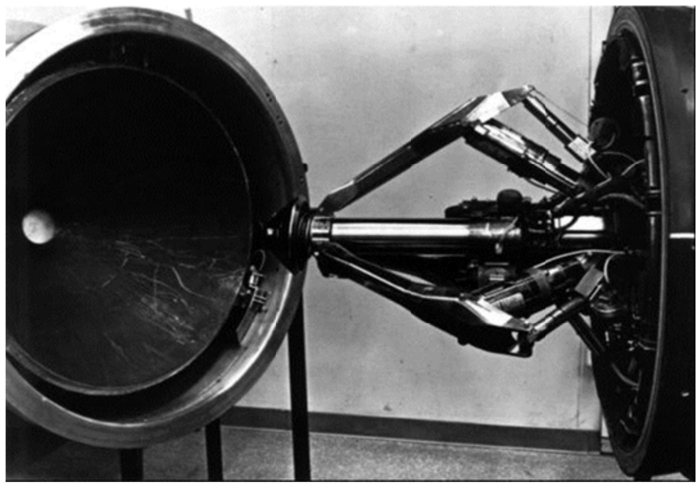


Fig 2: Apollo docking mechanism [12]

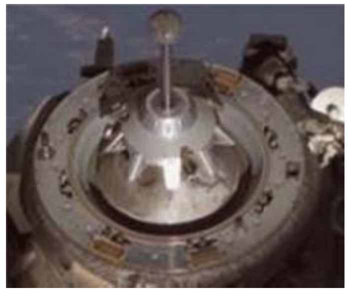
4.3. Soyuz Docking Mechanism

The probe, drogue, tension tie and a docking ring are the principal components of the Soyuz docking subsystem. Each module also contains a docking pressure hatch and a tunnel through which the astronauts will transfer from one vehicle to another (i.e. if required). Figure 3 shows the extended configuration of the probe

The docking maneuvers are controlled by the commander through short bursts of the reaction control engines on the active vehicle. He is aided in maneuvering his craft by the crewman alignment sight, an optical device something like the range finder of a camera which is mounted at a rendezvous window.

Before the docking maneuvers begin a crewman in the Chaser Module activates a switch which extends the probe. When the probe comes into contact with the drogue, it is guided into the socket at the bottom of the drogue. Three capture latches in the probe head then hold the two modules together. A crewman then activates the probe retraction device (a nitrogen pressure system located in the probe) which automatically pulls the two modules together. At contact 12 latches mounted on the Chaser Module docking ring are automatically activated to form a pressure-tight seal between the two modules.

The following figure shows the various modules of the Soyuz spacecraft. It is clearly visible that the docking system is attached to the top portion of the orbital module.



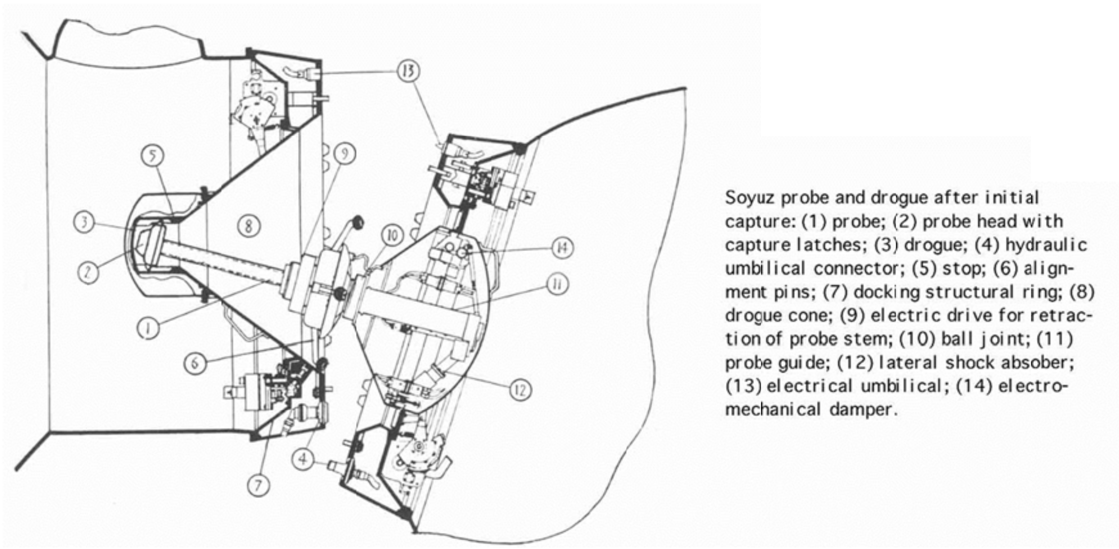


Fig 3: Extended probe of Soyuz docking mechanism [14]

4.4. Androgynus Peripheral Attachment System

The Apollo Soyuz docking mechanism is an androgynous system as shown in figure 4, called the International Docking Mechanism (IDM) – Androgynous Peripheral Attachment System (APAS)-75.

An androgynous system is one in which both male and female parts are identical, that is, both chaser and target spacecraft have the same docking mechanism. Depending on the mission scenario, either one can be made the active vehicle.

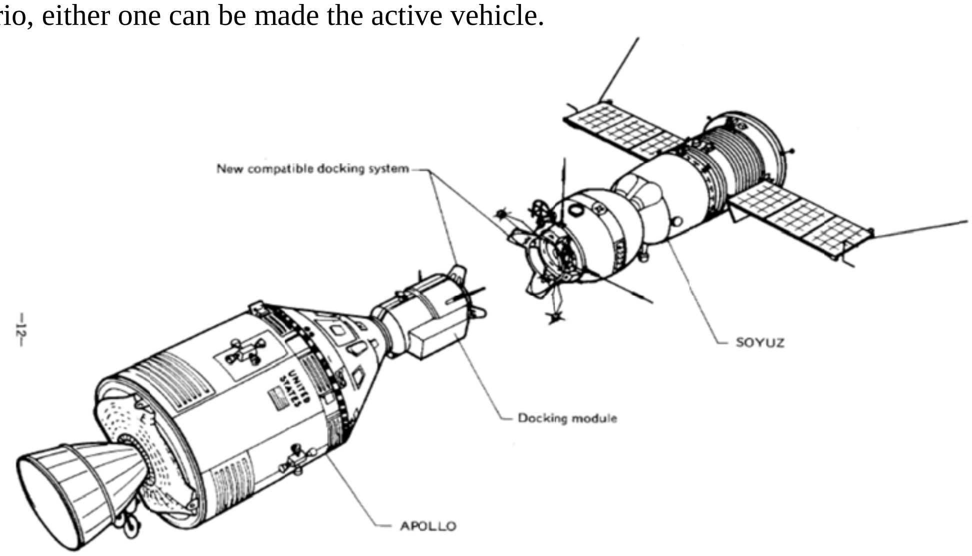


Fig 4: Docking of Apollo and Soyuz spacecrafts [5]

The active IDM consists of a guide ring, three guides, three capture latches, three body mounted latches, six attenuators, eight structural ring latches and a cable retraction system. Before docking, the active spacecraft extends the guide ring into the extreme forward position. This arrangement permits the accomplishment of all docking operations using the mechanisms of the active spacecraft only. During a docking attempt, the active IDM guides mesh with the passive IDM guides creating a centering effect. If the impact energy is sufficient, the attenuator geometry of the active IDM will comply, allowing the spring loaded capture latches of the active IDM to latch the body mounted latches of the passive IDM. The relative kinetic energy remaining after capture is nullified by the six attenuators. The stored energy in the attenuator springs returns the IDM to the initial configuration facilitating alignment between the docking vehicles. Initiation of the cable retraction mechanism draws the vehicles together, engaging the structural latches and rigidizing the docking interface. Figure 5 shows the APAS docking mechanism.

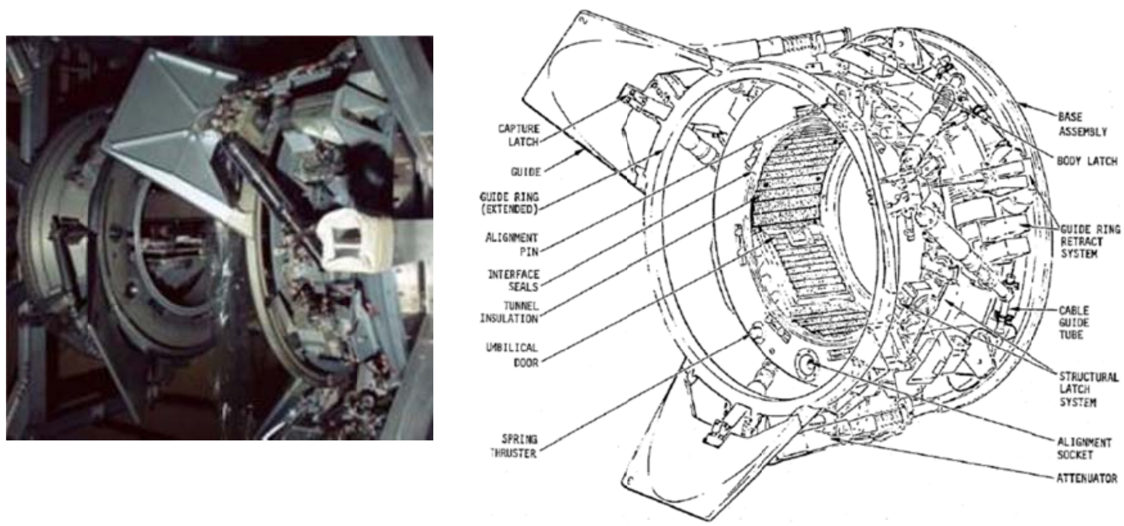


Fig 5: APAS 75 Docking Mechanism [14]

This was the first docking mechanism which paved the way for the first international collaboration between the two technological giants in the field of spacecraft docking mechanism. The details of approach parameters are given in table 1.

Table 1: Approach parameters of APAS-75 docking [5]

Description	**Minimum**	**Maximum**	**Units**
Longitudinal axis displacement			300mm
Roll	-7	7	deg
Pitch	-7	7	deg
Yaw	-7	7	deg
Roll Rate	-1	1	deg/s
Pitch Rate	-1	1	deg/s
Yaw Rate	-1	1	deg/s
Vx	-0.1	0.1	m/s
Vy	-0.1	0.1	m/s
Vz	0.05	0.3	m/s

Subsequent to this development major advancements were made in this type of docking mechanism. The next version of the APAS docking mechanism came to be known as APAS-89 was launched in the year 1989, which had the same number of petals but facing inside. Ball screw based hexapod was configured and compression springs were implemented.

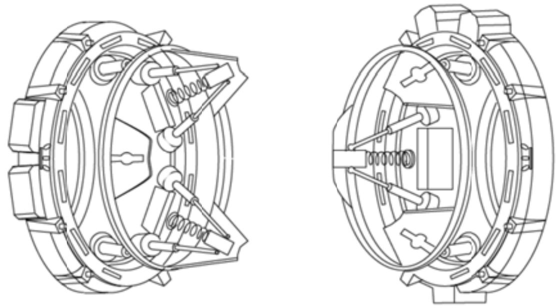


Fig 6: APAS 89 configuration used on Mir [15]

Later when APAS was adopted for Space Shuttle in the year 1995, it was further modified and a new version was introduced called as APAS 95 as shown in figure 7.

Fig 7: APAS 95 configuration for space shuttle [16]

Chinese docking system was a bought out system wherein they purchased the Russian Docking hardware. They used it on Shenzou spacecraft and demonstrated their docking capabilities

4.5. Common Berthing Mechanism (CBM)

This is the most extensively used docking mechanism on ISS. It provides several variants for docking of structures and vehicles for the expansion of the ISS and transfer of materials which include

1) Segment to segment attachment system (SSAS)
2) Rocketdyne Truss Attachment System (RTAS)
3) Modified Rocketdyne Truss Attachment System (MRTAS)
4) Module to Truss Segment Attachment System (MTSAS)
5) Carried Attachment System (CAS)
6) Mobile Transport (MT) to Mobile Base Servicer (MBS) Interface

Apart from the automated berthing mechanism there are a few manually operated berthing mechanisms also available:

1) Manual Berthing Mechanism (MBM)
2) Exposed Facility Berthing Mechanism (EFBM)
3) Exposed Facility unit.

Functioning and working of all these types of dockings can be seen in reference 10. Apart from several attachment systems, a generic Common Berthing Mechanism (CBM) for international space station has two parts. One is called as the active ring attached to one spacecraft and passive ring attached to the other spacecraft. Mission profile of the spacecrafts defines which one to have active and which one to have passive. The active ring contains the Actuation system hardware components including controller and bolt & latch actuators [3]. Each Active CBM (ACBM) contains:

i Control panel assemblies
ii 4 capture latch assemblies
iii 16 power bolt assemblies.

The bolt actuators are used to secure the bolts with a maximum preload of 8755 kgf. The actuators used for latch and bolt are identical but for the mounting interfaces. The details of the actuators are given in the following table.

SL No.	Description	Values
1	Motor type	3 phase, 10 pole Brushless DC motor
2	Feedback device	Hall effect sensor
3	Gear ratio	1242:1
4	Output torque capability	395Nm
5	Torque speed characteristics	180Nm upto 2min @ 0.5RPM

Fig 8: Active and passive rings of the common berthing mechanism [17]

4.6. International Docking System Standards- IDSS

It was in December, 2008 when a collaborative initiative was taken to develop standards for the docking systems to enable cost sharing while targeting long term goals of International Space Station. An attempt was made to replace all the CBM modules with low impact docking system. In the year 2010 rather than developing a new docking system a standard was formulated which would allow anyone to design a docking system for ISS [22]. The first version of International Docking System Standards- IDSS Interface Definition Document (IDD) was release in September 2010 [2]. This document provided the details of the basic geometry and design parameters which help the other design agencies to develop a compatible docking system for ISS programme.

Table 1. Initial contact conditions

Initial Condition	Limiting Value
Closing (axial) rate	0.05 to 0.10 m/sec
Lateral (radial) rate	0.04 m/sec
Pitch/Yaw rate	0.20 deg/sec (vector sum of pitch/yaw rate)
Roll rate	0.20 deg/sec
Lateral (radial) misalignment	0.10 m
Pitch/Yaw misalignment	4.0 deg (vector sum of pitch/yaw)
Roll Misalignment	4.0 deg
Notes: 1. Initial contact conditions are independent and are to be applied simultaneously, with the exception that the lateral rate at the vehicle cg resulting from the combination of lateral (radial) rate and the pitch/yaw angular rate should not exceed the lateral (radial) rate limit. 2. Mean closing (axial) rate may be adjusted depending on vehicle mass combinations. Refer to *Table 3-2: Vehicle Mass Properties*. 3. Post contact thrust may be used to achieve necessary capture performance. 4. Lateral (radial) misalignment is defined as the minimum distance between the center of the active soft capture ring and the longitudinal axis of the passive soft capture ring at the moment of first contact between the guide petals.	

Approach Parameters [6]

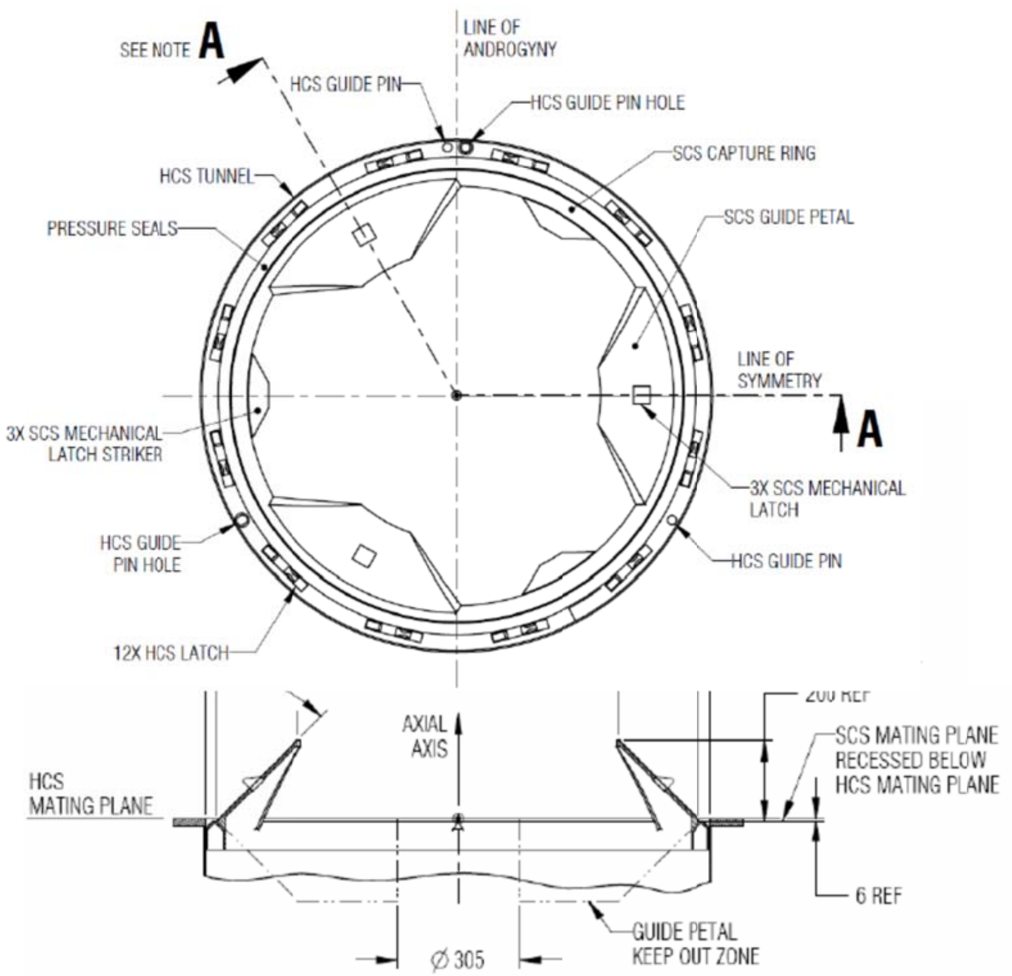


Fig 9: Androgynous docking interface [6]

4.7. International Berthing and Docking Mechanism (IBDM)

The International Berthing and Docking Mechanism (IBDM) is a contact force sensing, magnetically latched for capture, low impact docking system, capable of docking and berthing large and small vehicles developed by ESA. Figure 10, shows the drawing of IBDM mechanical design

Fig 10: IBDM mechanical element's configuration

IBDM does not incorporate a capture latch and rather has magnetic strikers. These strikers are electromagnetically actuated and they perform the capture action for the low impact docking.

Based on the stiffness characteristics it can be concluded that docking of light docking vehicles would not be possible with the IBDM. Thus the vehicles approaching with less inherent kinetic energy will have very less margin for controlling with respect to the impact forces in order to align the docking platforms. Vehicles with mass ranging between 2 to 21 tons under the given errors and velocity values can successfully dock with IBDM.

Table 2. Docking misalignments and velocity tolerances [4]

Description	**Minimum**	**Maximum**	**Units**
Roll	-5	5	deg
Pitch	-5	5	deg
Yaw	-5	5	deg
X	-5	5	cm
Y	-5	5	cm
Roll Rate	-0.5	0.5	deg/s
Pitch Rate	-0.15	0.15	deg/s
Yaw Rate	-0.15	0.15	deg/s
Vx	-1	1	cm/s
Vy	-1	1	cm/s
Vz	-10	-5	cm/s

4.8. NASA Docking System (NDS)

In April 2012, work was initiated towards the realisation of a new docking system which would amalgamate the APAS Russian system of docking and provide a soft platform similar to the low impact docking mechanism. This was named as Soft Impact Mating and Attenuation concept (SIMAC). The purpose of the NDS is to provide the means by which two spacecraft can establish a pressurised, man rated physical connection for the passage of people and resource between two spacecraft. The three major subsystems of the NDS include a Soft Capture System (SCS), a Hard Capture System (HCS) and a Docking System Controller.

Few requirements were stipulated for the design of this docking system. One such requirements was that Hard mate assembly/hard capture system shall be as per the International Docking System Standard IDSS Interface Definition Document (IDSS IDD). Figure 11 shows the components and configuration of SIMAC

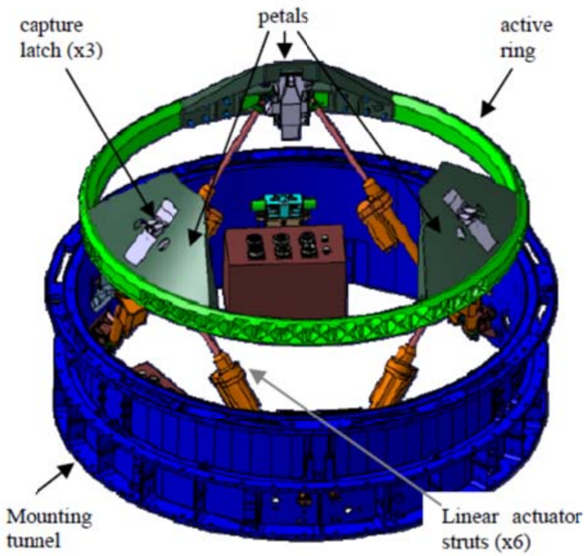


Fig 11: Components and configuration of SIMAC [7]

The approach parameters for NDS-SIMAC are given in Table 3.

Table 3. Approach parameters [7]

Initial Conditions	Limiting Value
Closing (axial) rate	Varies with vehicle mass combinations(3)
Lateral (radial) rate	0.15 ft/sec(4) (0.045 m/s)
Angular rate	0.15 deg/sec about NDS X axis; vector sum of 0.15 deg/sec about NDS Y and Z axes
Lateral (radial) misalignment	4.2 in. [106 mm]
Angular misalignment	4.0 degrees about NDS X axis; vector sum of 4.0 degrees about NDS Y and Z axes

4.9. ETS VII: Orihime and Hikoboshi Docking Mechanism for Soft Docking

The Engineering test Satellite was launched on November 28, 1997.

- Chaser Satellite : Hikoboshi ~ 2500 kg, 2m x 2.3m x 1.8m
- Target satellite Orihime ~400 kg, 1.5m x 1.7m x 0.7m

Both the satellites were launched as one, and later separated in orbit to perform rendezvous and docking (RVD) operations.

The docking mechanism consisted of claws on the chaser satellite and handle bars on the target satellite. The chaser spacecraft had three docking latch modules at 120 degrees apart. Each latch module had two motor driven latches. The target spacecraft had three passive handle bars at 120 degrees apart.

ETS VII had the following navigation sensors:

– GPS Receiver (GPSR) – Range > 500m

– Rendezvous laser Radar (RVR) – Range :2m – 520m
– Proximity Sensor (PXS) – Range : < 2m

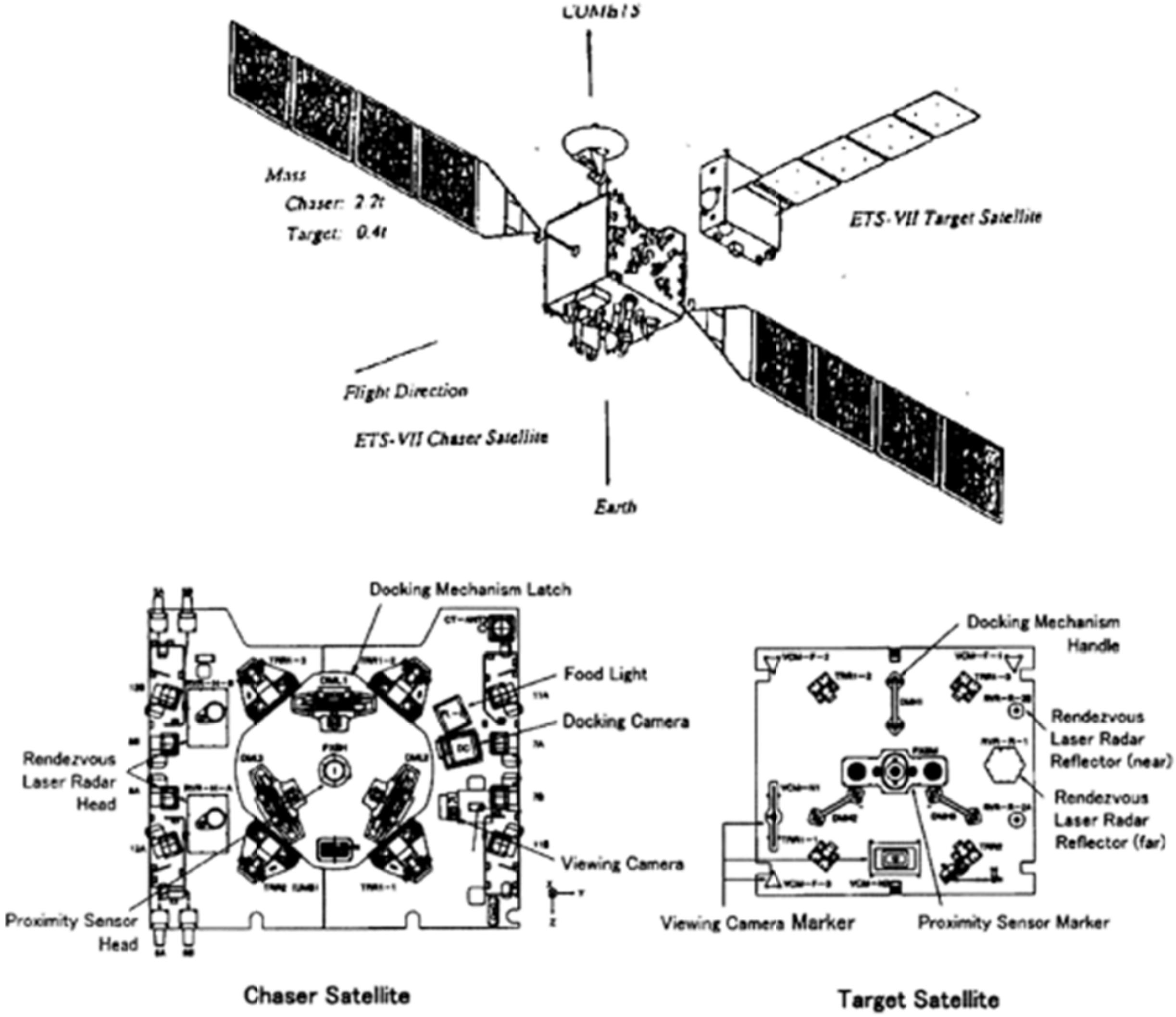


Fig 12: Configuration of ETS 7 docking spacecraft [18]

4.10. Orbital Express: ASTRO-Next SAT

The Orbital Express was launched in 2007. It consisted of two satellites, a prototype servicing satellite, Autonomous Space Transport Robotic Operations (ASTRO), and a surrogate next generation serviceable satellite (NextSat). They had the ability to berth and to dock to each other on orbit through a grappling arm that is attached to ASTRO or by three-pronged Starsys docking mechanism.

- ASTRO
  Height = 70 in, Width = 69 in, Solar array span= 220 in.
  Weight 2100 lbs (952.5kg) un-fuelled, Propellant weight = 300 lb (136kg)
- NEXTSAT
  Height = 40 in, Width = 39 in, Solar array span= 83 in.
  Weight 500 lbs (226.8kg)

The capture system consists of an active side and a passive side. The active side contains the grappling arms and the drive system; this side would normally be part of the supply spacecraft. The passive side provides capture features and a sensor to indicate proper engagement of the grappling arms; this side would normally be a part of the client spacecraft.

The approach parameters of the docking mechanism is given in table below.

Parameter	Value
Axial Capture Distance	6 inches
Angular Capture Misalignment Tolerance Pitch/Yaw Roll	 ± 5degrees ± 5degrees
Lateral Misalignment Tolerance	± 2 inches
Linear contact velocity Tolerance	3 cm/s
Preload	2500lbf
Capture Time	< 10s
Capture and Latch time	< 240s
Interface Outer diameter	<18 inches
Active Mass	< 50lbs
Passive Mass	< 25lbs

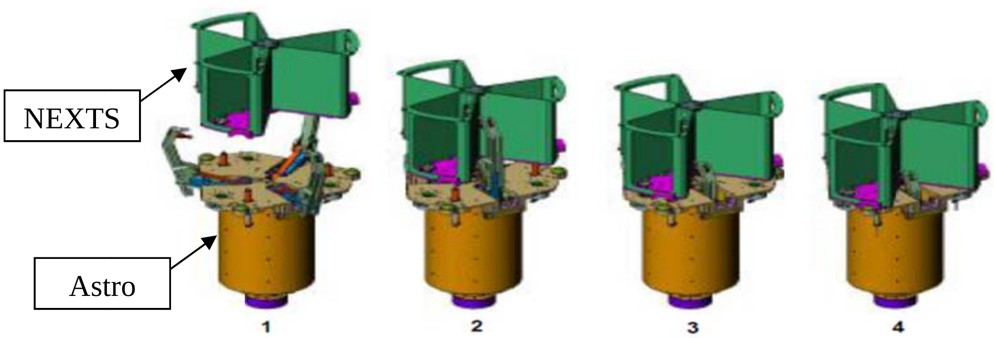


Fig 13: Stages of capture of the orbital express capture mechanism [19]

4.11. Mini AERCam

(Miniature Autonomous Extravehicular Robotic Camera)

The spherical Mini AERCam Free Flyer is a nanosatellite-class Free Flyer intended for future external inspection and remote viewing of human spacecraft as shown in figure 14. It is 7.5 inches (19 cm) in diameter and weighs approximately 10 pounds (5 kg). The Mini AERCam on the other hand has a magnetic docking system for automated deployment docking and recharge at a parent spacecraft.

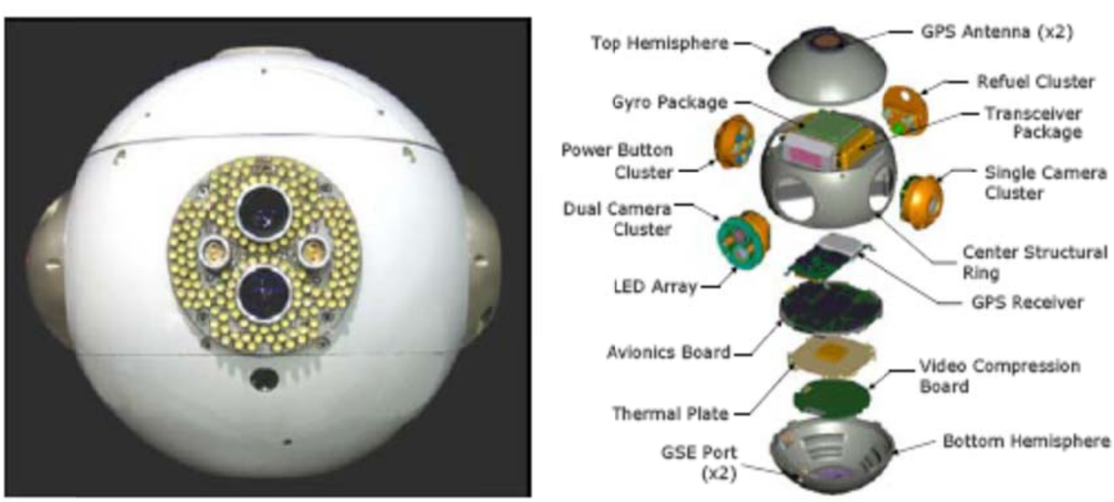


Fig 14: Mini AERCam configuration [20]

Docking Mechanism:

The subsystems developed include (1) a docking port, designed for the larger spacecraft, which contains an electromagnet, a ball lock mechanism, and a service probe; and (2) a docking cluster, designed for the smaller spacecraft, which contains either a permanent magnet or an electromagnet as shown in figure 13. The capture envelope for this system is approximated by a 5-in. (12.7-cm) cube centered on the front of the docking-port electromagnet and within an angular misalignment of <30°. Thereafter, the magnetic forces draw the smaller spacecraft toward the larger one and this brings the spacecraft into approximate alignment prior to contact. Mechanical alignment guides provide the final rotational alignment into one of 12 positions. Once the docking vehicle has been captured magnetically in the docking port, the ball-lock mechanism is activated, which locks the two spacecraft together. At this point the electromagnet(s) are turned off, and the service probe extended if recharge and refueling are to be performed. Additionally, during undocking, the polarity of one electromagnet can be reversed to provide a gentle push to separate the two spacecraft. This system is currently being incorporated into the design of Mini AERCam vehicle.

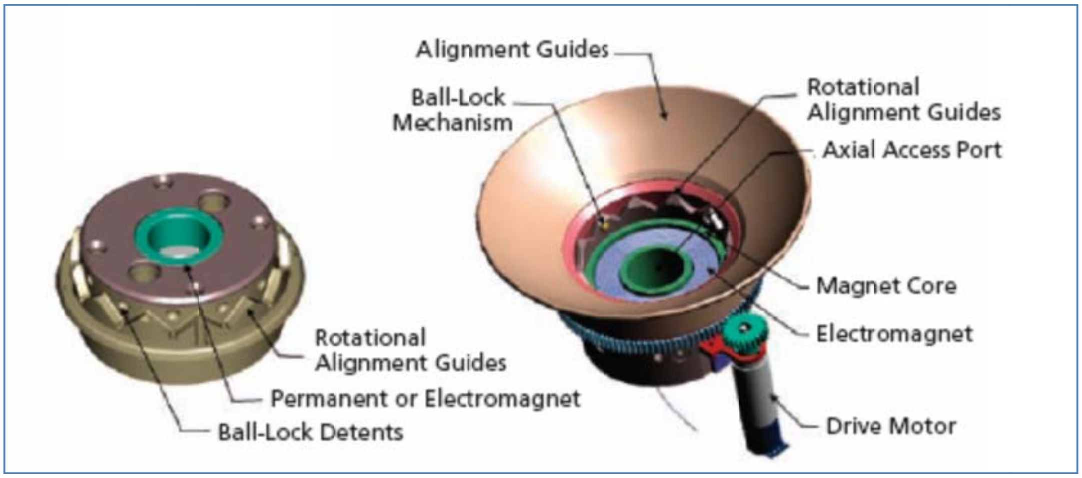
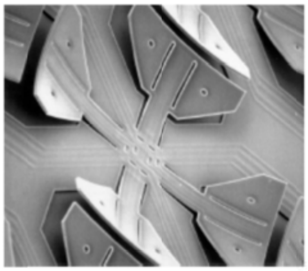


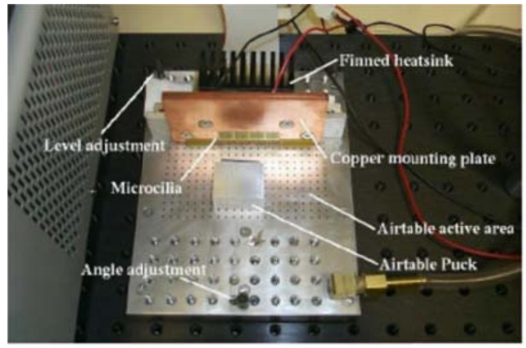
Fig 15: Docking mechanism configuration [20]

4.12. Docking Mechanism Using MEMS Actuators

Ongoing research focuses on using MEMS cilia arrays for precision docking of ***pico-satellites.*** As the size of a satellite shrinks their ability to carry fuel and power is reduced. It is expected that this will force micro-satellites to dock frequently to replenish their resources. Since the time spent docking subtracts from the micro-satellites' mission time, this procedure should be as simple and quick as possible. When docking micro spacecraft there are two primary tasks: attaching the micro-satellite to the larger craft, and orientating the satellite to connect fuel, data and electrical services. The first of these tasks is largely the domain of the micro-satellite and is dependent on how quickly velocity adjustments can be made, and on the specific attachment mechanism. The second task is made simpler and faster by the micro-cilia surface. Using micro-cilia to perform the delicate final orientation and positioning of the satellite will greatly speed up the docking operation because the entire satellite, with its fixed connections, could be mated to fixed connections on the main satellite. This alleviates the use of flexible and cumbersome umbilical cords and attendant positioning systems. A further benefit of using micro-cilia as a docking surface is a reduction in mass compared to other docking and alignment techniques.



Scanning electron microscope view of a single micro cilia motion cell ~ 1mm long and wide



Experimental setup

Fig 16: MEMS based docking mechanism [21]

The arrayed actuators are deformable microstructures that curl out of the substrate plane as shown in figure 16. The curling of the actuators is due to the different CTE of the polyamide layers that make up the bimorph structures. For these devices the top layer CTE is greater than the bottom CTE. The thermal stress from this interface causes the actuator to curl away from the substrate at low temperatures and towards it when heated.

The micro-cilia arm is placed into motion using a heating resistor, sandwiched between the two polyamide layers. When an electric current is passed through this loop, the temperature of the actuator increases, and the structure deflects downward. This produces both horizontal and vertical displacements at the tip of the micro-cilia. Objects in contact with the surface of the array are made to move by coordinating the deflections of many actuators.

5 Conclusion

This paper addresses the evolution of docking mechanisms from the 60's, to the present and that in the near future. The salient aspects of the docking approaches along with typical specifications have been illustrated. It may be noted that the immense potential of space docking technology for expanding the horizon of the activities of the human kind in the extra terrestrial frontier is multifold. The massive investments made by the space faring nations in developing this technology is a standing testimony for its importance in the decades to come.

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Provisional decision: 15 Apr. 2015
Final version submission: 31 May 2015
Final decision: 15 Jul. 2015

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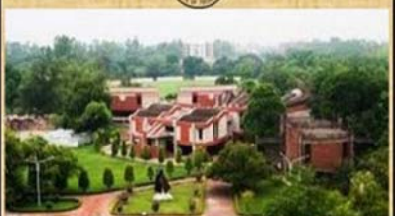

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The Department of Mechanical Engineering, IIT Kanpur, under the aegis of the Association for Machines and Mechanisms (AMM), and International Federation for the Promotion of Mechanism and Machine Science (IFToMM) is hosting the2nd International and 17th National Conference on Machines and Mechanisms (iNaCoMM 2015). The convention will be held on campus during December 16th- 19th, 2015.

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The International Society for Productivity Enhancement (ISPE) and College of Engg. & Management, Kolaghat, WB, India are proud to announce the 28th International Conference on CAD/CAM, Robotics and Factories of the Future. The organizing committee is calling all researchers, engineers and scientists around the world to contribute to the conference. Poster submissions are also encouraged reporting on work in progress. Full papers are invited in, but not limited to, the following topics:

A. Product Development and Sustainability
B. Modeling and Simulation
C. Automation, Robotics and Handling Systems
D. Supply Chain Management and Logistics
E. Advanced Quality Systems Tools and Quality Management
F. Advanced Manufacturing Processes
G. Human Aspects in Engineering Activities
H. Emerging Scenarios in Engineering Education and Training
I. Smart Factories

Conference proceedings

Conference proceeding will be published by Springer through double blind review process as per Springer guidelines. Also a few selected and best papers will be again published in several reputed journals such as ***Journal of Computational Design & Engineering (Elsevier), International Journal of Bio-Mechatronics & Biomedical Robotics (Inderscience), International Journal Manufacturing Technology & Management (Inderscience), International Journal of Mechatronics, Electrical and Computer Technology (IJMEC), Universal Scientific Organization, Journal of Mechatronics and Intelligent Manufacturing (Nova science)***

Tentative Speakers

Chief Guest

- Prof. Raj Gill, Middlesex University, UK

Guest of Honour

- Professor Hrishi Bera,Colombia and South Bank University, UK

Tentative Speakers

- Professor Chanan Syan, University of West Indies
- Professor Andrew Yeh-Ching NEE, National University, Singapore
- Prof. Ashish Dutta, IITK
- Dr. Subir Kumar Saha, IITD
- Prof. Ashitava Ghosal, IISc, Bangalore
- Dr. Prabir K Pal, DRHR, BARC, Mumbai
- Dr. D. N. Badodkar, BARC, Mumbai
- Dr. Pradeep Kumar, VSSC, Thiruvananthapuram

Key Dates

30th May 2015: Second Call for Full Papers
30th July 2015: Acceptance of PAPERS
15th August 2015: Final acceptance of paper
31st August 2015: Final paper submission

Conference Chair

Prof Dipak Kumar Mandal
College of Engg. & Management, Kolaghat,
Mail: dipkuma@yahoo.com, dkm@cemk.ac.in