Booster Attachment Mechanism for Pilotless Target Aircraft

V K Pandey[1]
R&DE (E), DRDO
Kalas, PO Dighi, Pune, India-411015
Email: vinu2pme@rediffmail.com

G K Sarkar[2]
R&DE (E), DRDO
Kalas, PO Dighi, Pune, India-411015
E-mail:sarkargk@rediffmail.com

***Abstract*— Pilotless Target Aircraft (PTA) is an unmanned aerial vehicle, which is used as a target for weapon systems like radar guided and heat seeking Surface to Air missiles, Air to Air missiles, shoulder launched missiles, land and ship based anti aircraft guns. PTA is launched from a zero length launcher with the help of a booster. The booster carries high energy explosive, which is highly inflammable. Attaching booster to the PTA is cumbersome and risky job. Three crew were necessary to attach the booster to the PTA, manually. It was quite dangerous for life of the crew to work with such high energy explosive for approximately 10 minutes in not so easily accessible position. The job has become more risky as it is to be carried out at a height of approximately 2.5m from the ground level. To minimize human interference and to provide safety of the crew, a mechanism has been provided. The booster is attached to the inclined PTA using three pins, as before. In this paper, a mechanism is presented which has been successfully designed, developed and presently being used. The straight line mechanism, which is a modified four bar mechanism has been used. In this mechanism, one zero force link has been attached at the midpoint of the crank, to achieve perfect vertical motion. Two more degrees of freedoms has been introduced in the mechanism to obtain the motions of tilting and sliding. The motion is achieved using three hydraulic actuators operated from a distance of 7 m, which is quite safe. The booster is attached using the combined motion of these three actuators. The attachment of booster has thus become very easy and safe by the use of this mechanism.**

Keywords*— *pilotless target aircraft: launcher; booster; mechanism; hydraulics

I. INTRODUCTION

'The more you sweat in peace, the less you bleed in war' says the well-known principle of military training. The adage assumes greater significance in times of cut back in peacetime allocations. The real challenge is in maintaining preparedness and skill levels of Armed Forces within budget appropriations that are shrinking in real terms. While a great deal of weapon training can indeed be imparted by simulated missile launches and silent gun laying exercises, it is widely accepted that the final sharpening of skills can be achieved only by frequent live firing exercises. An Aerial Target simulating the enemy aerial threats is required for such exercises. To be cost effective, the philosophy adopted in aerial targets is that it is a physically scaled down model of the aerial threat simulating the Radio Detection and Ranging (Radar) and Infra Red(IR) signatures of the aerial threat. It is also accepted that a near miss in training will be an actual hit in combat.

Aerial Targets discussed here can be of two types. Manned Aircraft Tows and Unmanned Aircraft Tows. Manned aircraft tows are mainly used for air defence gun practice in both land and ship based configurations. It is also used for combat pilots gunnery training. In the case of manned aircraft tows, the tow targets can be reeled on to the winch systems and used for carriage and deployment. Unmanned aircraft tows in addition to gunnery training are used for missile engagements. Being uninhabited aircraft, there is no concern for pilot safety as the UAV caters to inadvertent shooting down of the towing aircraft. UAVs - as aerial targets are also used for weapon engagement training, where in the higher speed, higher maneuverability achievable is exploited to improve the quality of training. Obsolete jet aircraft are also converted into drones and used as aerial target for certain special training and weapon system evaluation requirements.

Aerial Targets can also be expendable or reusable types. There can be low speed and high speed targets. Low speed aerial targets are propeller driven systems used for elementary training. They are characterized by their low cost of operations and simplicity of design and operations. High speed targets are turbojet driven complex systems realizing high subsonic speeds, high telecommand ranges etc. They are mainly used for advanced training purposes.

Low cost aerial target systems normally tow sleeve targets or banners for gunnery training whereas high speed targets tow targets for weapon engagement.

Applications of Aerial Targets cover training of personnel and also test and evaluation of weapons.

A. Role and Operation of PTA

PTA - an aerial target system is a training aid. It realistically simulates enemy aerial threat and permits proficiency assessment and improvement of weapon crews. Weapon crews cover land or ship based air defence crews and combat pilots. Weapons cover guns and missiles. PTA is an unmanned aerial vehicle, which is launched from the ground or a ship in a weapon training range. It is commanded and piloted from the ground by a controller and presented for weapon engagement. It has variable speed and maneuverability to simulate enemy threat. It tows a sub target to be cost effective. All weapon engagements take place with the tow target, which has

Radar/IR signature augmentation, to make the system cost effective.

PTA is reusable. Towards the end of its life PTA can be used in clean configuration which permits higher speeds and maneuverability to impart better training to combat pilots. PTA can also be used to test and evaluate new weapons.

B. LAUNCHING OF PTA

There are many methods of launching PTA. Out of these most common methods of launching are given below.

A. Conventional launch: In this, PTA is launched using conventional run way. Thus more space is required for launching.

B. Unconventional launch: In this method runway is not required and the PTA can be launched from carrier vehicle itself. This requires less space for launching and sometimes even zero length. In this category, different methods are used to launch PTAs. Common methods in this category is as under

a) Booster launch: In this method, launching is carried out using booster power. This launch is generally done where high power, high initial velocity is required. This is zero length launch and requires booster for every launch. High explosive propellants are used in this type of launch. They are ignited using some sort of igniter. They produce high explosive energy during burning of the propellant. Consequently, this generates high temperature in the range of approximately 3000 K for very short duration.

b) Catapult Launch: In this, stored energy is used to get the desired kinetic energy. In this case, required run way is very small of the order of few meters. Catapult may be achieved using hydraulic or pneumatic or combination of both. Some speed enhancement mechanism may be used to get desired velocity.

C. Launching system: There are two types of launchers which are generally used.

a. Static Launcher: this launcher is fixed on the ground and attachment of booster is carried out manually without any problem as the booster is attached at the comfortable height from the ground.

*b. Mobile Launcher***.** In this, all components of launching system are mounted on High Mobility Vehicle (HMV). The height of the platform is about 1.6 m above the ground. First, PTA is placed on the transport supports called front support and rear support as shown in Fig. 1 and with the help of the hydraulic cylinder of front support, the PTA is made inclined to the desired 14 degree of launch angle. During the launch position, the center support is used and front support in kept in horizontal position as shown in Fig. 2. The booster is attached to the PTA at the desired angle depending upon which configuration it is being launched i.e. with tow body or without tow body. There are three booster attachment points on the airframe of the PTA. Two at the rear which are changeable as per the configuration and third at the front (fixed) as shown in Fig. 3. The front point of the attachment is 0.9 m (approx.) from the vehicle platform. Thus, the booster is attached at the height of 2.5 m above the ground that to at an angular position which is cumbersome and risky job as it carries high energy explosive.

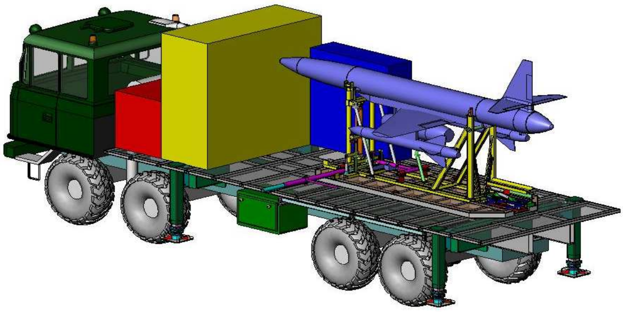


Fig .1. PTA in Transport Condition

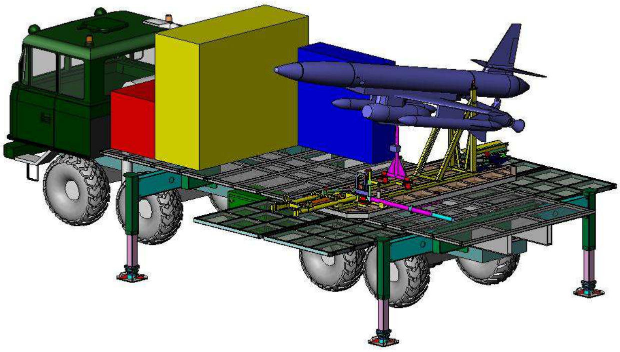


Fig. 2. PTA in Launch Condition

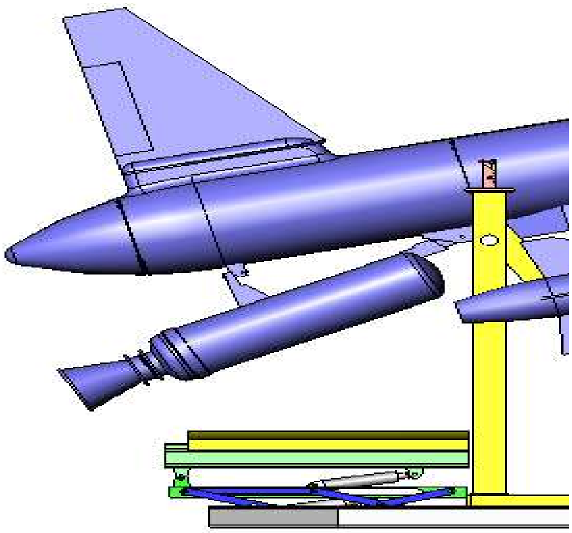
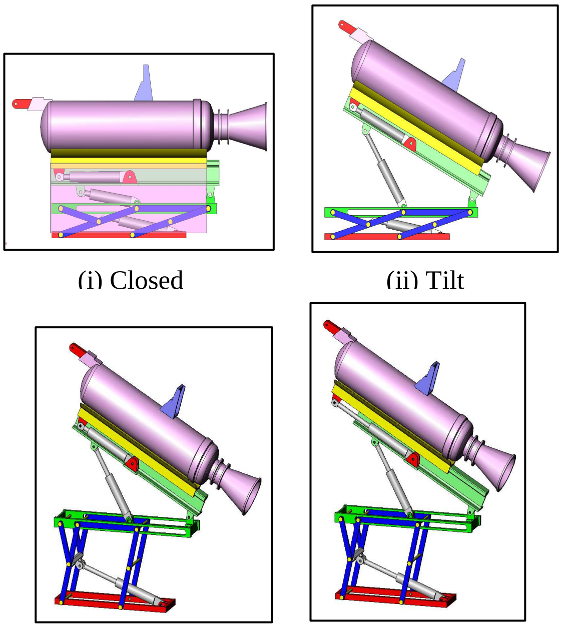


Fig.3. Three Attachment Points of Booster with PTA

C. INTRODUCTION OF MECHANISM

In order to reduce manual interference and contact with the booster, a mechanism is provided. This mechanism has got three motions i.e. lifting, tilting and pushing. By proper operation of three motions, the booster can be attached to the PTA. Earlier, many mechanisms have been used to lift the object. Ayaulym Rakhmatulina et al[1] used Nurbery scissors mechanism, Tian Henyu et al[2] developed scisoors mechanism with cylinder location in various orientations using Pro E software. Other researchers are worked related to this mechanis[3-6]. In this paper, a mechanism for the attachment of booster is being presented. Booster is to be placed manually over the mechanism. With the help of proportional control valves, smooth integration of Booster with PTA will be



(i) Closed (ii) Tilt (iii) Lift (iv) Push

Fig. 4. Sequence of operations - Booster

achieved. The working principle of booster attachment mechanism is shown in Fig 4.

Max mass of booster = 70 kg

The mass of the cylinders and the Mechanism = 130 kg

Total mass of the system = 200kg (approx)

Launch angle of PTA= 14°(say)

Angle between the booster and the PTA

Clean configuration = 12 (without tow bodies)

Tow configuration = 8 (with tow body)

For Booster attachment mechanism, using solid work software[4] the following requirement is finalized.

Max lift required = 311 mm

Max tilt required = 26° (14+12) (without tow bodies)

= 22° (14+ 8) (with tow bodies)

Max push required = 200 mm(approx)

II. SYNTHESIS

A. Lifting Mechanism: This mechanism is used for the lifting of the booster absolutely vertical position. This is achieved using a mechanism as shown in Fig 5. This mechanism is a modification of four bar parallelogram mechanism with one end of zero force link attached at the mid of crank AC and another end attached to the horizontal link which slides with the link opposite to fixed link of the parallelogram as shown in Fig. 5. The vertical

linear motion of the horizontal link is obtained without angular motion. The mechanism is synthesized using graphical method. The following points are kept in mind while synthesizing the mechanism.

a) In fully extended condition of the cylinder, the mechanism should not have sufficient gap to impart tilting motion and while launching, the rear bottom most point of the PTA should not interfere with the mechanism.

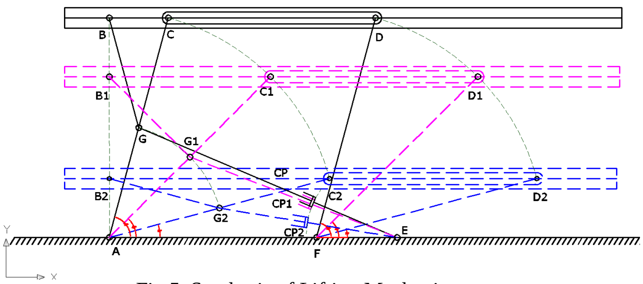


Fig.5. Synthesis of Lifting Mechanism

b) The booster mechanism should be symmetrical about the PTA axis as booster is to be attached symmetrically.

c) It should be able to attach booster in both configuration i,e. with and without tow bodies .

d) Hydraulic actuator dimensions i.e. closed center length, open center length, dead length and stroke should be enough to raise and lower the mechanism.

Calculation of Degree of Freedom: As per Grubler's criterion for Planar Mechanism [8]

$DOF=3(N-1) -2J_1-J_2$

Where, DOF = Degree of freedom or Mobility

N = Number of Links

J_1 = Number of lower pairs

J_2= Number of higher Pairs

In this case, N= 8

J_1 =10

J_2 = 0

Total degree of freedom = 3(8-1) - 2X10 - 0

DOF = 1

Dimensions AC =DF

AF = CD

GA= GB=GC

The angle of rotation of crank for required lift is obtained based on the calculation as shown in Fig.6. The position at raised condition corresponding to ABCDEFG at 75 degree , intermediate position A1B1C1D1E1F1G1 at 45 degree and A2B2C2D2E2F2G2 at 15 degree(Closed Position) are shown in Fig. 5 The cylinder stroke, Open center length(OCL) and closed center length(CCL) are calculated based on this requirement. The biggest advantage of this mechanism is that the force required by the cylinder to lift the booster is independent of the location of the booster on the platform[7].

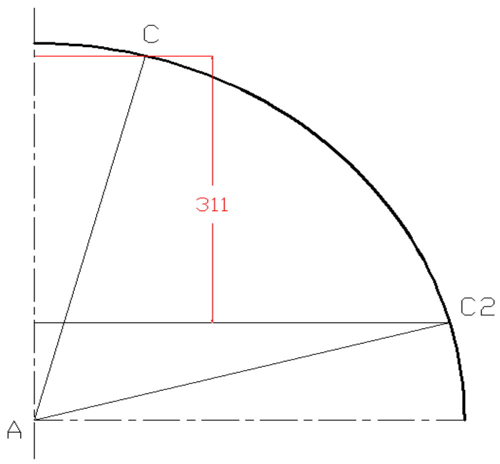


Fig.6. Calculation of Lift of the mechanism

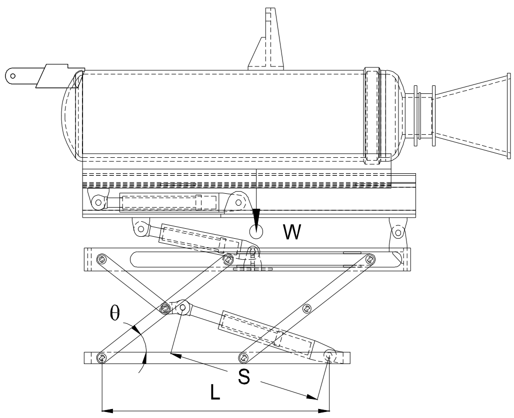


Fig.7. Free Body Diagram

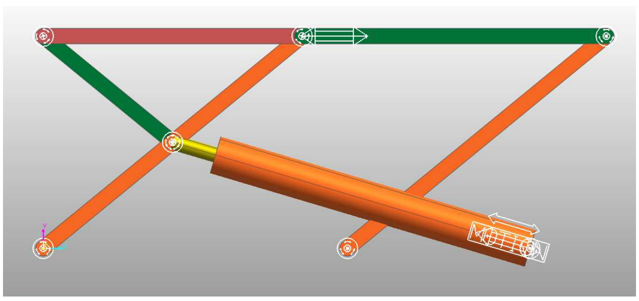


Fig.8. THE MODEL DIAGRAM USING RECURDYNA 6.2

Calculation of force required by the cylinder: By applying the principle of virtual work, Cylinder force can be computed. For this purpose, the free body diagram is shown in Fig. 7

Cylinder force F = WxS/L Cotθ

Where, W is Load =2kN

S = Length of cylinder pinned point

L= Cylinder horizontal distance AE

At Closed Condition:

θ_1 = 15° (approx)

S1 = 375 mm (approx)

Max. Compressive force = 4443 N= 4.4 kN

At fully opened condition:

Θ_2 = 75° (assume)

S2 = 560 mm

Min compression force =476.4 N

The same mechanism was analyzed using software RecurDyna 6.2 version. The model diagram is shown in Fig. 8.

The mechanism is analyzed using the software RecurDyna 6.2[9]. The Zero angular motion of the arrow point link is shown in Fig. 9. The figure shows that in all time the angle is zero. The behavior of the mechanism is analyzed using two type of motion. (a) 1mm/s uniform speed is given to the cylinder. (b) Speed is increased from to 1 mm/s gradually and the mechanism is analyzed. The zero force is coming on the Link GB as shown in the Fig. 10. The graph depicts also the forces coming on the the revolute joint C. It can be observed from the figure that the force is maximum at closed position and subsequently reduces as it moves upwards. The decrease in the force is steeper in case of proportional movement of the cylinder i.e. case 2, as can be seen if Fig.11 is compared with Fig. 10.

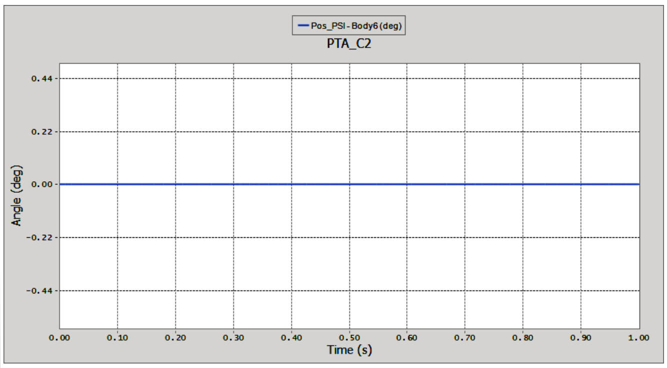


Fig.9. Angle vs Time for Link CB

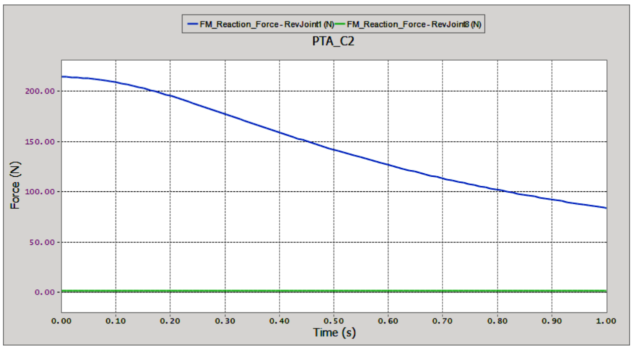


Fig.10. Force vs Time with uniform speed

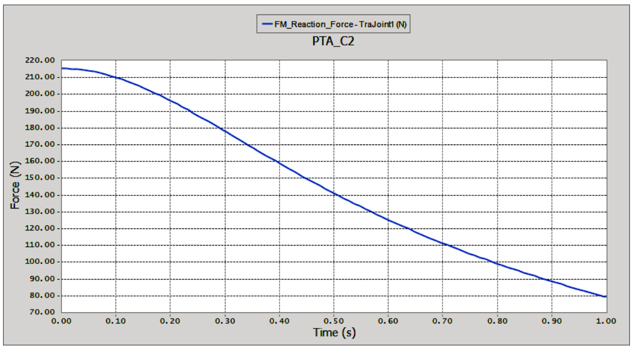


Fig.11. Force vs Time with proportional speed

4.2 Tilting Cylinder: The tilting operation of the mechanism can be achieved using a cylinder. The cylinder is attached in such a fashion that it can give desired angle with minimum stroke of the cylinder with highest moment. This is a one degree freedom mechanism used for tilting upto an angle of 26 degree. Using principal of virtual work, the cylinder force is calculated based on the free body diagram shown in Fig. 12.

Max compression cylinder force = 2000x450/126

= 7142 N = 7.142 kN

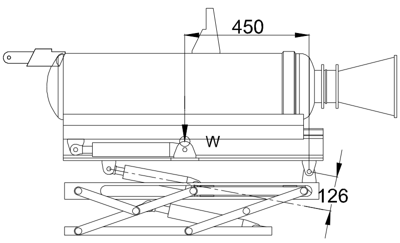


Fig.12. Free Body Diagram for Tilting Cylinder

4.3: Pushing Motion: The pushing motion is required to attach the booster. This mechanism is also having single degree of freedom. Nylon pads are provided to reduce friction and smooth functioning of the cylinder. The cylinder force is calculated as, Friction coefficient =0.4

Max tension / compressive force = $2 \times 10^3 \times 0.4$

= 800 N = 0.8 kN The three cylinders are used to provide three motions.

III. RESULT AND DISCUSSION

The three degree of freedom mechanism is sufficient to attach booster smoothly by only two men. The contact time with the booster is reduced drastically and thus the safety of human life is increased. The mechanism has been realized as shown in Fig. 13. It has performed all it functions successfully and the system has been accepted by the users after repeated performance trials. It is presently being used in the Mobile launcher and the complete system has been handed over to the users.

Fig.13 Realised Booster Mechanism (Closed condition)

IV. CONCLUSION

The mechanism made attachment of the booster very smooth and reduces risk of human lives. The booster attachment at height of 2.5 m above the ground was really a cumbersome job especially at an angular position. This mechanism made user life very comfortable and the operation can be controlled from 7 m away from its location. The route of hydraulic hoses is selected in such a way that there should be minimal exposure to the hea

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