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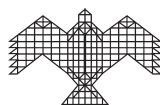
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China's Anti-ship Ballistic Missile Game Changer in the Pacific Ocean

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Summary

China's spectacular economic growth in the last decade has been accompanied by its impressive performance in the areas of space, missiles and warship building. Among the more remarkable of these has been its development of an Anti-Ship Ballistic Missile (ASBM), which according to experts, is intended to deter or target US aircraft carriers.

Western media and naval sources reacted with concern bordering on alarm to the reports of the development of the ASBM. There were also skeptics who strongly doubted China's capability to design and engineer such a missile along with the sophisticated technical infrastructure that its operation requires. However in May 2010 when a senior US Admiral declared that in his view the Chinese ASBM had reached "Initial Operational Capability", it was clear that talk of such an advanced weapon was not mere speculation.

This study was undertaken by a group at the National Institute of Advanced Studies to make an analytical assessment of China's capability to design and develop an Anti-Ship Ballistic Missile directed against an Aircraft Carrier Strike Group (CSG), and also the Chinese ability to create the technical infrastructure required to transform this missile into an operational weapon system.

In the last few years China has exerted itself to create a satellite-based system to provide large area surveillance and reconnaissance capabilities. It has launched various space-based sensors to get electronic, photographic and radar information over large ocean areas of interest. All these capabilities taken up in their entirety lead to the conclusion that they could have been created to obtain early warning of an approaching carrier strike formation.

While this system may not yet be complete, there is enough indication that it has reached an advanced stage. This may be the reason why the US has stated that the ASBM has entered the Initial Operational Phase. In addition to the space-based system there is an Over-the-Horizon (OTH) radar system that can give real-time information on the location of an approaching CSG. The study projects that the error in the location of the carrier from all these space and ground based assets for a missile to target an aircraft carrier can be conservatively estimated to be 25 km.

Information available in the public domain on the DF 21 missile has been analysed and an estimate made of the overall weight of a reentry vehicle that would be required if it were provided with maneuvering ability, an autonomous on-board radar, an onboard propulsion system with sufficient fuel for reaching a mobile target as well as other requirements such as aerodynamic surfaces for terminal phase maneuvers. With these stipulated capabilities, the reentry vehicle weight works out to 1700 kg.

For this increased warhead weight, the study has calculated the additional fuel weight and the increased dimensions of the first and second stages of a hypothetical DF21 derivative. Measurements and dimensional analysis of available images of the DF21 D show a close match with the study's predicted dimensions, which lends credibility to the claims made for the Chinese ASBM.

Overall, the study finds after careful analysis of its space-based capabilities, its OTH radar systems, its assessed C4ISR capabilities and the state of readiness of the DF 21 D missile that it appears that China has indeed achieved an asymmetrical equalizer to the US carrier- based power projection capability.

It would be rash to assume that this single factor gives China the regional supremacy it seeks. But China's ASBM has precipitated a fresh, critical appreciation of power relativities, and shaken the traditional view of the US Navy's unassailable superiority in the Pacific.

CHINA'S ANTI-SHIP BALLISTIC MISSILE GAME CHANGER IN THE PACIFIC OCEAN

Introduction

China's determined thrust towards world power status in the past decade and a half has evoked both interest and apprehension. With the erasure of its "century of humiliation" as a strong political and emotional driver, China has made rapid advances in all spheres of nation-building – social, technological, economic and military. While the progress in technology and military strength has been keenly watched by specialist China-watchers, its economic expansion has been the most visible manifestation of China's resolve to assume its place in the upper rungs of the international power structure.

China has a definite unfinished agenda. At the top of the list is the reclamation of territories that have (in the Chinese view) historically belonged to it, including the reunification of Taiwan with the mainland. In the attainment of these objectives the Western powers led by the USA are seen as major impediments. The US is the main adversary, with global dominance and military reach. More to the point, the US is the dominant power in the Pacific, and a direct threat to China's ambitions.

The first step in China's progress towards balancing the power disparity was the attainment of nuclear weapon status. China's nuclear strategy is not one of parity, but sufficiency. It has sought to apply a similar strategy in its neutralisation of the US domination of the Pacific. US military dominance is based on its power projection capability. The US Navy is the main instrument of this capability, and the core of its naval power are its carrier strike groups, or CSGs. Evidently China has concluded that the great equalizer would be a weapon that would neutralise the aircraft carrier (specifically, its air superiority) without committing its own inferior naval or air forces.

Research and feasibility studies to develop a ballistic missile specifically to target US Navy (USN) carriers began in the late 1990's and continued for a few years before reports about such studies were published in the open literature in China. The Anti-Ship Ballistic Missile (ASBM) was first officially mentioned in a US DoD report of 2005.[1] When the Office of Naval Intelligence reported in 2009 that the Chinese ASBM was probably nearing operational status, there were many articles and papers by

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[1]   Ronald O'Rourke, "China Naval Modernization: Implications for U.S. Navy Capabilities — Background and Issues for Congress; Theatre Range Ballistic Missiles", CRS Report for Congress; November 18, 2005 p 5 at http://fpc.state.gov/documents/organization/57462.pdf "Although ballistic missiles in the past have traditionally been used to attack fixed targets on land, observers believe China may now be developing TBMs equipped with maneuverable re-entry vehicles (MaRVs). Observers have expressed strong concern about this potential development, because such missiles, in combination with a broad-area maritime surveillance and targeting system, [14], would permit China to attack moving U.S. Navy ships at sea. The U.S. Navy has not previously faced a threat from highly accurate ballistic missiles capable of hitting moving ships at sea. Due to their ability to change course, MaRVs would be more difficult to intercept than non-maneuvering ballistic missile re-entry vehicles."

professional and other experts in the US that expressed alarm and called for positive counter-measures.[2] In May 2010 Admiral Willard, the C-in-C US Pacific Command stated that "the ASBM was probably very close to being operational." In December he confirmed his view that the ASBM had attained "Initial Operational Capability."[3]

Focus of this Paper

The operationalisation of a ballistic missile specifically targeting the central pillar of US naval power in the Pacific would obviously result in a major re-examination of regional stability equations. If this system is as effective as some observers fear, it would keep the US Seventh Fleet away from Chinese shores and enable China to act with impunity to achieve its long-term aim of Taiwan's reunification.

Chinese authorities have not made any claims about the technological breakthrough that the ASBM undoubtedly represents (or will represent when operationally proven). But civilian programmes on Chinese television, doctrinal papers outlining the concept of operational deployment of the ASBMs and other indicators have for the past several years regularly implied that China is on the threshold of a major successful techno-military innovation.

This paper seeks to make an assessment of the ASBM as a concept and the probability of it being an existential threat and a tactical deterrent to the US Navy's CSGs. The paper consists of three parts.

The first part is a technical overview of Chinese C[4]ISR with detailed reference to the space-based component of its capability to effectively maintain surveillance over a large ocean expanse. This part also contains a brief discussion of the missile fire control problem, the basic launch geometry, and the special features of targeting a warship formation at sea.

The second part examines the maneuvering requirements for a basic missile of the DF-21 type and assesses the modifications and enhancements required to an existing missile for it to meet the anti-ship mission profile. The results are compared with the actual images and data available on the DF 21D to establish whether the DF 21 could have been modified for the new role.

The third part discusses the impact that the ASBM would have on the current geo-political scenario, and on the military and strategic equation.

This is followed by a conclusions section which puts together all the three parts to provide an integrated perspective.

A set of technical overviews on the OTH radar, the Re-entry Vehicle and an imaginary scenario of the working of the ASBM against US targets as seen by the Chinese are provided in the Annexures.

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[2] Andrew S. Erickson and David D. Yang, "Using The Land To Control The Sea? Chinese Analysts Consider the Antiship Ballistic Missile", Naval War College Review, Autumn 2009, Vol. 62, No. 4

[3] Andrew Erickson and Gabe Collins, "China Deploys World's First Long-Range, Land-Based 'Carrier Killer': DF-21D Anti-Ship Ballistic Missile (ASBM) Reaches 'Initial Operational Capability' (IOC)",China SignPost™ #14, 26 December 2010 at http://www.andrewerickson.com/2010/12/china-deploys-world%E2%80%99s-first-long-range-land-based-%E2%80%98carrier-killer%E2%80%99-df-21d-anti-ship-ballistic-missile-asbm-reaches-%E2%80%9Cinitial-operational-capability%E2%80%9D-ioc/

1. Operational and Tactical Considerations

### 1.1 Direction of Threat and Surveillance Area

The maritime threat to China may emanate from a wide arc ranging from the north-east to the south. Geographical factors and other practical considerations such as the presence of commercial marine traffic and the limited sea room available in the southern sector may perhaps modify the likely threat arc to the north-east to south-east sector. In this sector the main US Naval bases are Yokosuka in Tokyo Bay and Yigo in Guam. Whereas Japan is close enough for a strike with very little notice, the Guam base is over 2500 kms distant. Considering that the mission radius of the F-18 Super Hornet (the US Navy's main carrier-borne attack aircraft) is about 750 Kms, China's aim would be to prevent a Carrier Strike Group (CSG) approaching to less than about 1000 kms off the coast. To be able to attack an approaching CSG at that distance, surveillance would probably be mounted 1000 to 1500 kms to seawards beyond the 1000 km limit mentioned; the area inside 1000 kms being left to shore-based tactical surveillance forces. (See **Fig. 1**)

1.2 Features of A CSG Formation

A typical CSG is a large combatant formation with one or two aircraft carriers, anti-submarine, air defence and missile defence destroyers and cruisers, as well as logistic ships. Together they may number from ten to fifteen units. Each carrier would have a complement of about 75 combat and reconnaissance aircraft, forming the main strike power of the force. In addition to

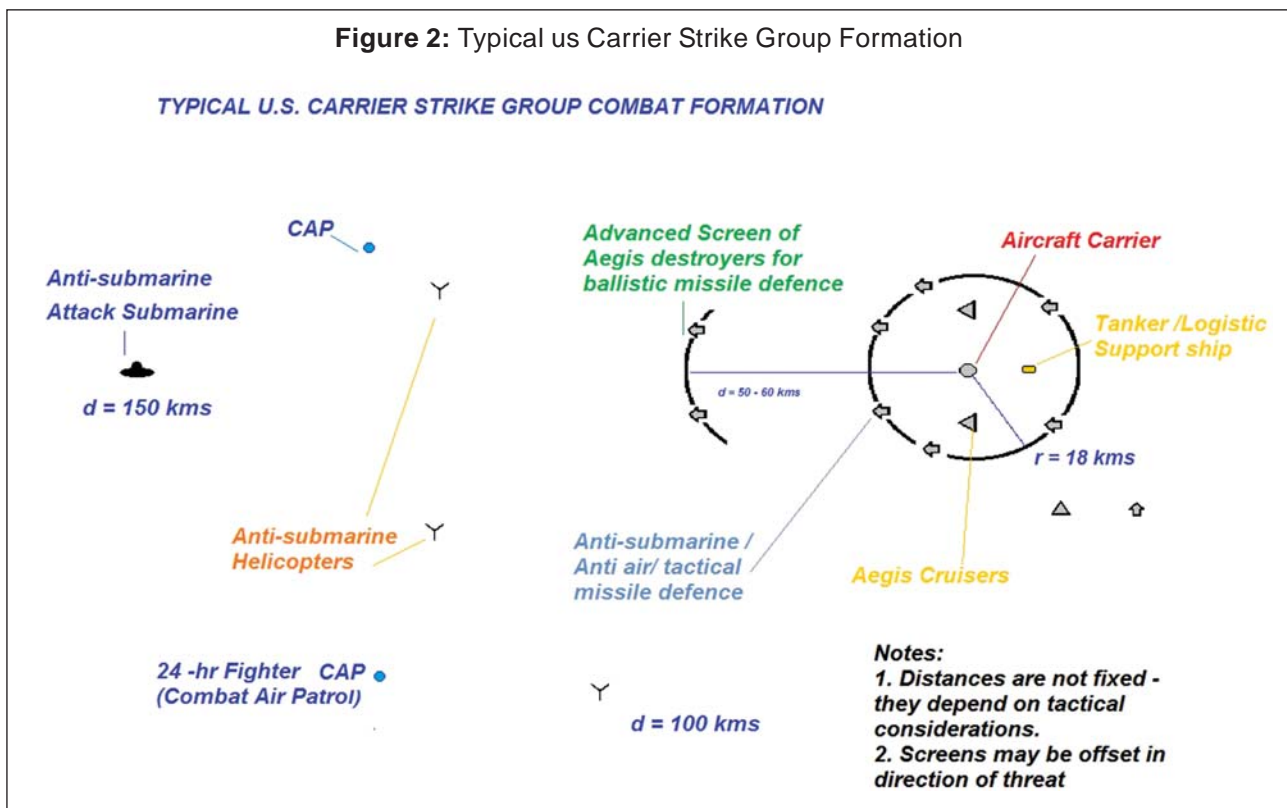**Figure 1:** Surveillance ARCS to Detect CSG
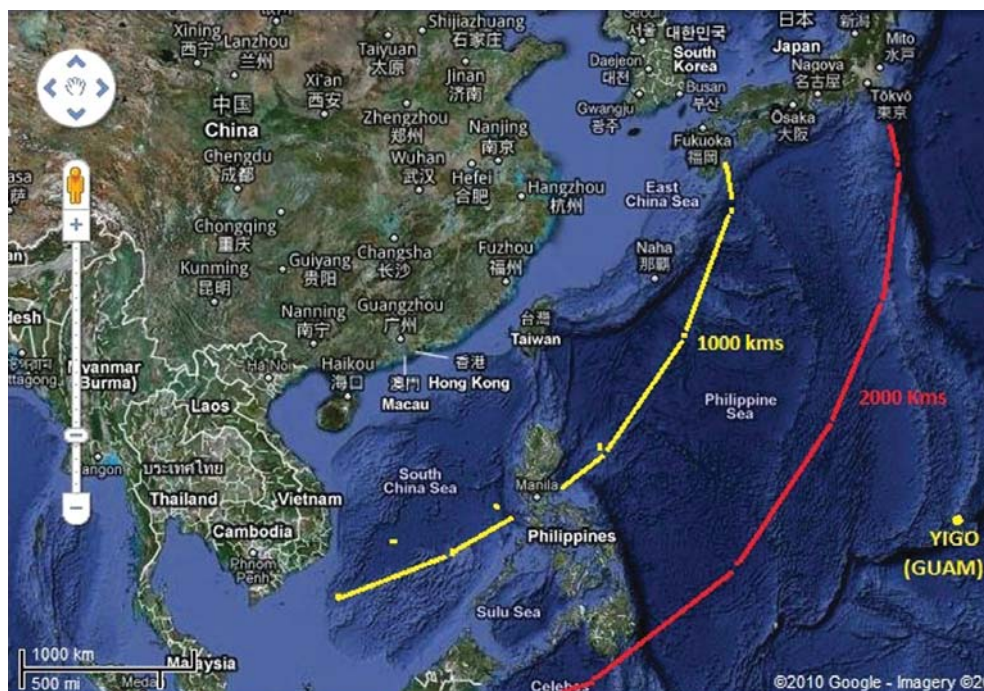
their defensive capabilities the warships are also heavily armed with guns and anti-ship and land-attack missiles. In the scenario of a ballistic missile threat there would also be BMD-capable destroyers and cruisers in the escort equipped with the Aegis system. The main part of the formation, without counting the advanced and distant support units, could be spread over an area of twenty kms radius, or over a thousand square kms. Even in peacetime, all warship formations are on combat alert, though at a lower level of readiness. At the slightest tension or warning, the level of preparedness is raised. This would mean that at all times there would be aircraft airborne from the carrier, on practice sorties or on continuous early warning and combat patrol tasks. Thus an operational CSG would be operating aircrafts round the clock.

The units of the formation would not all be following the same course and speed, but they would all hold to the same base course and speed. Thus there would be no significant relative motion differences, except in rare circumstances. All ships of the formation would be capable of high speeds and manouvres when alerted, such as in case of a missile warning.

The oceans today are busy waterways and are used by scores of transiting tankers and commercial ships at any given time. Many of these may be of a few hundred thousand tons displacement, compared to most US carriers which are in the high ninety thousand ton bracket. The flat deck of a tanker could look similar to that of an aircraft carrier. A sketch of a typical CSG formation is at **Fig. 2**.

Figure 2: Typical us Carrier Strike Group Formation

TYPICAL U.S. CARRIER STRIKE GROUP COMBAT FORMATION

CAP

Anti-submarine Attack Submarine

d = 150 kms

Anti-submarine Helicopters

24 -hr Fighter CAP (Combat Air Patrol)

d = 100 kms

Advanced Screen of Aegis destroyers for ballistic missile defence

d = 50 - 60 kms

Aircraft Carrier

Tanker /Logistic Support ship

r = 18 kms

Anti-submarine / Anti air/ tactical missile defence

Aegis Cruisers

Notes:
1. Distances are not fixed - they depend on tactical considerations.
2. Screens may be offset in direction of threat

These characteristics create problems of identification and target discrimination for surveillance and tracking radars, and of electronic countermeasures, terminal guidance and anti-missile defence penetration for an incoming ASBM.

2. Intelligence, Surveillance and Reconnaissance

2.1 Background

Only technical means of gathering intelligence, surveillance and reconnaissance missions are considered in this assessment. While there are differences in these tasks, they all deal with information about the position and movement of the target and can thus be lumped together conveniently for purposes of this discussion.

Timely target detection is crucial for the success of the ASBM system. This can be achieved through air, sea-based (including underwater) platforms, ground and space-based radar as well as other sensor systems. Together with the corresponding platforms, these form the essence of the C4ISR system.

2.2 Airborne and Sea-based Sensors

Airborne and Sea-based sensors (both surface and underwater) mounted on military aircraft, naval ships and submarines can be useful in maintaining surveillance and carrying out reconnaissance in specific areas for varying periods. China does have the means to deploy aircraft and ships with the necessary technical means to perform these tasks. At present there is a dearth of nuclear submarines in the PLA (N) to carry out dedicated reconnaissance missions,

but judging by the ongoing submarine construction programmes, it may be expected that with time these shortages will be made up to enable the PLA (Navy) to allocate SSNs for this task.

Aircraft and naval assets are however best used when the likelihood of the target's passage through a particular area in a finite period of time are known or can be reasonably estimated. They cannot be effectively used to maintain round-the-year surveillance over vast swaths of the ocean, which is what the ASBM system requires. These units can be used more economically and efficiently in nearer regions, perhaps within a 1000-km range of the coast.

2.3 Over-the-Horizon (OTH) Radars

China has been working on Over-the-Horizon (OTH) radars since the late 1960s, but significant progress has really taken place in the last decade. Initially developed as part of the Anti-missile defence measures, OTH radars are now widely used for surface surveillance as well. China's development of OTH radar has been widely reported in both the international as well as the Chinese media and includes two types of radars:

♦ sky wave radars which depend on backscatter from the ionosphere and are commonly referred to as OTH-B radars;
♦ the ground or surface wave type radars (OTH-SW) which have a much shorter range.

As reported in the Hong Kong media the China National Electronics Import and Export Corporation released details of an OTH-B radar installation in 2007. Performance details of the radar are not available from authenticated

sources, but conservative estimates place the minimum detection range at about 800 kms, and the maximum detection range at about 3000 kms.

China is reported to have at least one Over-the-Horizon (OTH-B) sky-wave radar system operational[4], which could be used in the early warning role against an approaching CSG. A map showing likely areas that can be kept under surveillance for the OTH-B radar is at Fig. 3.[5]

China's current surveillance assets include a number of both coastal OTH-SW and inland-based OTH-B radar systems. In the context of

this paper only OTH-B radars are considered as the area of our interest is beyond 1000 kms. These give detection and tracking capability against surface ships as well as aircraft.

The OTH radar has two parts – a transmitter part and a receiver part. These are normally separated from each other by distances of 100 to 200 km. Each part consists of a long linear line of individual elements spread out over a distance of 2 to 3 km. The OTH radars operate at frequencies of between 5 to 30 MHz. The locations of these radars are well known. An evaluation of the performance of these radars by radar experts is available in Annexure 1.

Figure 3: Surveillance ARC for OTH (B) Radar

4   Eric Hagt and Matthew Durnin, "China's Antiship Ballistic Missile - Developments and Missing Links"; Naval War College Review, Autumn 2009, Vol. 62, No. 4 http://www.chinasecurity.us/pdfs/others/Hagt&Durnin.pdf "Detecting the carrier at great distances would depend on early-warning systems, such as sky-wave, over-the-horizon (OTH) radar, or electronic signals intelligence, that would give a general idea of the target's geographic coordinates.[49] "There is substantial evidence that China has at least one over-the-horizon backscatter (OTH-B) system up and running.[50] It could be used to identify targets at long range, although with a tracking error of from twenty to forty kilometres..."

5   Sean O'Connor,"OTH(B) Radar Viewing Area"; IMINT & Analysis; Nov 11 2008, http://geimint.blogspot.com/2008_11_01_archive.html

One such OTH B radar is located close to Shenchang. The transmitter and receiver of this OTH B radar are separated by about 100 km. The transmitter is located at $27^0 47'$ latitude and $120^0 46'$ longitude. The receiver is located at about $27^0 45'$ latitude $120^0 45'$ longitude. Its location along the south eastern coast of China close to Taiwan also provides China with the coverage that controls access routes to Taiwan from the North East and South East Pacific very similar to the coverage shown in Figure 3. It covers most if not all the areas from where threats can emanate.

While OTH-B radars have huge range advantages, they have their own limitations. The chief limitation is their poor spatial resolution. The resolution achievable depends on the Doppler separation of the scatter signals. This depends not only on the relative movement of objects of interest but also has a contribution from the ionosphere. As mentioned earlier, the relative motion between the ships in a CSG is not significant. However there would be aircraft sorties every two hours or so, which would be detectable. The OTH resolution along the direction of range would be better than their resolution across the range.

An additional difficulty with OTH radars is they are prone to disturbances from ionospheric conditions. They would therefore require frequent calibration from independent data collected on the ionosphere. This may require an additional dedicated facility.

Based on our evaluation of the performance of OTH radars along with recent developments in various signal processing techniques, the spatial resolution achievable by an OTH radar

system has been conservatively assessed to be about 20 km. This means that the CSG location could be anywhere within a 20 km radius based on the tracking data supplied by the OTH. Obviously this accuracy is insufficient for guiding a missile to the target. The location of the CSG using the OTH is only possible once it comes within 2000 to 3000 km of the OTH. Even then it may be difficult to pick up the CSG from the other objects like commercial shipping that will be present in the broad expanse of the ocean.

These two issues make it necessary to have other independent means of supplementing the target data. To strike the CSG either the target has to be located after the launch of the missile by a sensor on-board the missile or the target must be located very precisely just before the launch of the missile. Air and sea-based platforms may be in a position to provide such independent inputs. However, continuous monitoring by air and sea based platforms at such distances from the shore pose major constraints in respect of logistics, operations and expenditure and are not practical. Consequently, reconnaissance and electronic intelligence satellites are the only means of obtaining independent and precise CSG location inputs.

3. The Space Component of the ASBM System

Together with OTH radars, the space component of the system is one of the vital requirements for the viability of China's ASBM capability. Three elements of the space-based system would be of critical importance. These are:

♦ Reconnaissance Satellites equipped with Synthetic Aperture Radars (SAR).

- Reconnaissance satellites providing high resolution optical imagery.
- Large Area Electronic Ocean Surveillance Satellites to locate and track targets of interest in the Ocean.

3.1 Reconnaissance Satellites with Synthetic Aperture Radar (SAR)

Reconnaissance satellites equipped with Synthetic Aperture Radar will provide all-weather as well as day and night information on targets of interest. To cover the globe on a continuous basis a large number of such satellites would be needed. A smaller number (two to three) may be adequate to cover a more limited theatre like the Pacific Ocean approach to China. These satellites must be able to cover a fairly large area and may need to scan areas of interest on either side of the satellite track. They would provide confirmation of any preliminary identification of a potential threat. They may need to work in two different modes – a coarser resolution broad swath mode to cover a larger area and a more limited swath with higher resolution to clearly identify a target of interest. Many commercial civilian satellites have demonstrated these capabilities. SAR has very high data transmission rates. It also consumes a lot of processing power to convert the data into products that can be used for identification and confirmation. These require associated ground and some space infrastructure which could become vulnerable points in the overall architecture of the system. For global coverage many satellites equipped with SAR follow near polar or sun-synchronous orbits. Space-based SAR systems are more difficult to build and operate than optical imaging payloads. Satellites are likely to be heavier and also may need higher on-board power.

3.2 Reconnaissance Satellites Carrying High Resolution Optical Payloads

The SAR constellation may require support from more conventional optical and infra-red sensors on satellites. Such satellites are also generally in sun-synchronous orbit and carry Charged Couple Device-based digital camera systems. Data rates especially for metre and sub-metre resolution are likely to be high, but processing of the data and speedy delivery capabilities have already been demonstrated in many national and commercial systems. Building such a sensor that can also be moved around on either side of the satellite track, may not be too difficult for a mature space power like China. The ground infrastructure is easier to build and operate as compared to the SAR system. The optical sensor on the satellite is a complement to the SAR, as by itself it may not provide continuous coverage because of both cloud cover and night time coverage requirements. Therefore without the SAR component the system may not be as credible.

3.3 Orbit, Resolution & Coverage Considerations for SAR and Optical Sensors

The tradeoff between resolution and swath covered on the ground will determine the orbit of both the SAR and the optical sensor satellites. Orbits generally are fairly low earth orbits ranging from about 500 to 900 km. Sun-synchronous orbits with inclinations between 97 and 98 degrees are obvious choices as they

provide the additional benefit of global coverage and data for many civilian applications as well.

Currently for typical sun-synchronous orbits the maximum swath widths for both SAR and optical payloads would be about 100 km. This means that there would be large gaps in the ground coverage between satellite passes that could even last a few hours. There could be gaps of several days before the satellites come back to survey a given area of the sea. Increasing the number of satellites and spacing them out could provide continuous coverage. However this increases both the cost and the complexity of operations. For continuous or near-continuous surveillance of areas of interest a large area ocean surveillance capability is a necessity for the ASBM to pose a serious threat to a CSG.

3.4 Large Area Ocean Electronic Surveillance Satellites for Location and Tracking

The third and most important space-based component of the ASBM system is a satellite system that can provide large area coverage of the oceans on a continuous or near-continuous mode. Such satellites monitor electronic communications and other radio-emissions from ships to locate them in the open sea. They collect data from a fairly large area through a number of broad-band onboard receivers. To locate the ship the same emission has to be collected from at least three different satellites. If the positions of the satellites and the time at which the signal is detected by the different satellites are known then the location of the source of emission can be fixed. Higher altitude orbits would cover larger areas. A typical system involves three

satellites separated by known distances in a 63.5 degree inclination orbit. The reason this orbit is chosen is because at this inclination there is no precession of the apogee or perigee of the satellite. The relative distances between satellites as well as their relative altitudes remain unaltered making it easier to determine the position of the emitter.

Some information on the configuration of satellites launched by the US to collect electronic intelligence on ships that were located over the horizon may be worth looking at to understand Chinese capabilities and intentions. Following a series of experiments in the early 1970's the US deployed an operational ocean surveillance system starting from 1976. This has since been replaced by a more advanced system starting in 1990.

The ocean electronic surveillance system deployed by the US consists of three co-orbiting satellites each of which is equipped with wide-band receivers operating in different frequencies that can detect electronic emissions from ships. The US satellites were in 1100 km circular orbits inclined at 63.5 degrees. The three satellites are separated from each other by known distances, typically 50 to 240 km. The same signal is received by the three different receivers at different times. This enables the determination of position accurately if the separation between the satellites is known and the time signals on all three satellites are synchronised. Successive determination of positions may also enable the velocity of the target to be determined. The received data is transmitted to ground stations for further processing from where it is sent to a command and control facility. From here it is disseminated to the user.[6]

Four clusters of three satellites in different orbital planes separated by 60 to 90 degrees provided the US with global as well as real time coverage of all areas. Each cluster would typically cover a zone of 3500 km radius. Even with a single cluster, a second fix on an object of interest would most probably be available in the next orbit – typically about 107 to 108 minutes later. The large coverage also makes revisit periods quite short. If the area of interest is limited to the western Pacific a single cluster of co-orbiting satellites at 63.5 degrees inclination may provide the required surveillance capability to detect and track a CSG well before it comes within the range of the OTH radar.

The geometric arrangement between the satellites is crucial for accurate prediction of location and velocity. To take care of the risk of this geometry breaking down over the poles, one of the satellites in the cluster may have a slightly different apogee. The advantage of the 63.5 degree orbit is that this apogee will remain fixed and not change with time. Thus the relative positions of the satellites and the distances between them may not change from orbit to orbit. A 63.5 degree orbit and three co-orbiting satellites separated by a small distance is a typical signature of such a system.

These three space components would be key elements in the proposed Chinese OTH-based ASBM system. Other space-based assets such as communications satellites, navigation satellites

and data relay satellites would complement these capabilities. With the exception of a Tracking and Data Relay Satellite the Chinese have all these capabilities. These other elements are assumed to exist and not specifically addressed in this paper.

3.5 China's Space Based Ocean Reconnaissance & Surveillance Capabilities for an ASBM Mission

Table 1 provides data on the more recent launches by China along with their orbit details. This has been prepared from information available in open sources.[7]

From the various parameters listed in the above Table we can clearly see that Yaogan 1, Yaogan 3 and Yaogan 10 seem to have similar characteristics. Public reports available including information provided by China suggest that this is a satellite carrying a Synthetic Aperture Radar (SAR).

By the same token it appears from Table 1 that Yaogan 2, Yaogan 4 and Yaogan 7 are similar. As per Chinese sources these appear to be the optical reconnaissance component of the ASBM system.

The launch of the Yaogan 9A, 9B and 9C satellites on the 5th of March 2010 on a specially designed Long March launcher is the first deployment of China's Large Area Ocean Electronic Surveillance

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6   For a description of the US Ocean Surveillance ELINT system please see Major A. Andronov, "The US Navy's White Cloud Space-borne ELINT System", Zarubezhnoye Voyennoye Obozreniye (Foreign Military Review), No.7, 1993, pp. 57-60. http://www.fas.org/spp/military/program/surveill/noss_andronov.htm

7   http://www.astronautix.com/craft/yaogan.htm. http://en.wikipedia.org/wiki/Yaogan and http://www.sinodefence.com/space/spacecraft/yaogan.asp

Table 1: Ocean Reconnaissance – Recent Chinese Satellites

Satellite	Date	Launch Time GMT	Launch site	Orbit inclination degree	Apogee Perigee km	Period (minutes)	Comments
Yaogan1	26/4/2006	22.48	Taiyuan	97.8	630 x 627 km	97.3 minutes.	SAR
Yaogan2	25/5/2006	07.12	Jiuquan	97.8	655 x 631 km	97.6 minutes	Optical;
Yaogan3	11/11/2007	22.48	Taiyuan	97.8	629 x 628 km	97.3 minutes	Same as 1 SAR
Yaogan4	1/12/2008	04.42	Jiaquan	97.9	654 x 632 km	97.6 minutes	Same as 3 Optical
Yaogan5	15/12/2008	03.22	Taiyuan	97.4	496 x 486 km	94.4 minutes	Higher resolution - Optical
Yaogan6	22/4/2009	02.55	Taiyuan	97.6	512 x 512 km	94.9 minutes	Higher resolution - Optical
Yaogan7	9/12/2009	08.42	Jiaquan	97.8	659 x 623 km	97.5 minutes	Same as 1, 3 - Optical
Yaogan8	15/12/2009	02.31	Taiyuan	100.5	1204 x 1193km	109.4 minutes	Optical large area coverage?
Yaogan9A	5/3/2010	04.55	Jiuquan	63.4	1107 x 1074km	107 minutes	Naval ELINT
Yaogan9B	5/3/2010	04.55	Jiuquan	63.4	1107 x 1074km	107 minutes	Naval ELINT
Yaogan9C	5/3/2010	04.55	Jiuquan	63.4	1107 x 1074km	107 minutes	Naval ELINT
Yaogan10	9/8/2010	22.49	Taiyuan	97.8	635 x 637 km	97.3 minutes	Same as 1,3 SAR
Yaogan11	21/9/2010	02.42	Jiuquan	NA	NA	NA	NA

system. The orbital parameters such as altitude, orbital inclination and orbital period are very similar (1100 km altitude, 63.5 degree inclination, 107 minutes) to the first generation US deployment of a Large Area Ocean Electronic Surveillance System. The radius of coverage of such a system would be about 3500 km – which will provide notice of an approaching CSG well before the threshold of 2000 km for the ASBM is crossed. Even a single constellation will be able to monitor the CSG and provide advance notice to China. In tandem with SAR and optical reconnaissance satellites the ability to detect and track the CSG well before the 2000 km limit is reached can now be termed real.

This deployment of the three-satellite Ocean ELINT capability marks the transition from potential capability to operational capability. The Chinese may or may not deploy more clusters spaced appropriately so as to provide continuous coverage around the world. Even without it, detection and identification of a Carrier Strike Group is possible well outside the presumed 2000 km Chinese threshold. The deployment and operation of this constellation may well be the real reason for the US to term the ASBM as having reached "Initial Operating Capability".

The data also seem to suggest that the sun-synchronous Yaogan 5 and Yaogan 6 satellites are very similar and closely follow each other. These may be optical reconnaissance satellites with a slightly higher resolution than the Yaogan 2, Yaogan 4 and Yaogan 7 satellites. Public statements attributed to Chinese experts suggest an improvement in resolution from about 2 m to 1.6 m.

Yaogan 8 stands out as an outlier which is not similar to any of the other satellites in the Table. It is possibly a satellite with a wide area coverage optical sensor with a relatively coarser resolution.

3.6   Review of Chinese Capabilities in Space

Figure 4 provides an overview of satellites launched by China on a yearly basis. Figure 5 provides the same data as Figure 4, but in cumulative terms. [8]

From about 5 satellites per year – typical numbers for the period 1990 to 2000 – the number of launches has increased to reach 20 satellites in 2010.

Figures 6 and 7 provide annual and cumulative space launch vehicle information for the period 1970 to 2010.

This data makes it clear that China's capabilities in space have significantly accelerated in the last ten years. It is clear from the above analysis that China has progressed substantially on the Space

Components of ASBM capability.[9] With the establishment of the three-satellite Large Area Ocean Electronic Surveillance System, China has moved from potential capability to operational capability. This is a major advance and is the most likely reason for the US concern and the upward revision of its assessment of the status of China's ASBM.

4   Assessment of Integrated C4ISR

While the capabilities of the missile are crucial, of equal importance to the effectiveness of the ASBM system is the combined efficiency of the Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) network. Figure 8 provides an overview of the various information sources that need to feed into an integrated C4ISR to target an ASBM.

China has made strides in this field, especially since the Gulf war when this was declared as the major focus of the PLA's modernisation. The functioning of the ASBM system requires another level of technological sophistication, with a quantum increase in real time data-processing demand and the need for fusion of diverse data networks such as satellite-based sensors, ionospheric data, communication and data networks, missile tracking radar as well as ground-based, sea-based and airborne intelligence sources. However not only the Chinese but the US Department of Defense also believe that this will be well within China's capability. Last year's Annual China Report to

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8   Data from http://members.jcom.home.ne.jp/ttsujino/space/chinalist_e.htm

9   For an overview of China's space capabilities see Steven A. Smith, Lt Col, USAF, "Chinese Space Superiority? – China's Military Space Capabilities and the Impact of their Use in a Taiwan Conflict", Research Report Submitted in Partial Fulfilment of Graduation Requirements, Air University Air War College, 17 February 2006.

Congress by the DoD specifically stated so in the context of China's ASBM capability.[10]

**Figure 4**: Satellites Launched from Chine 1970-2010
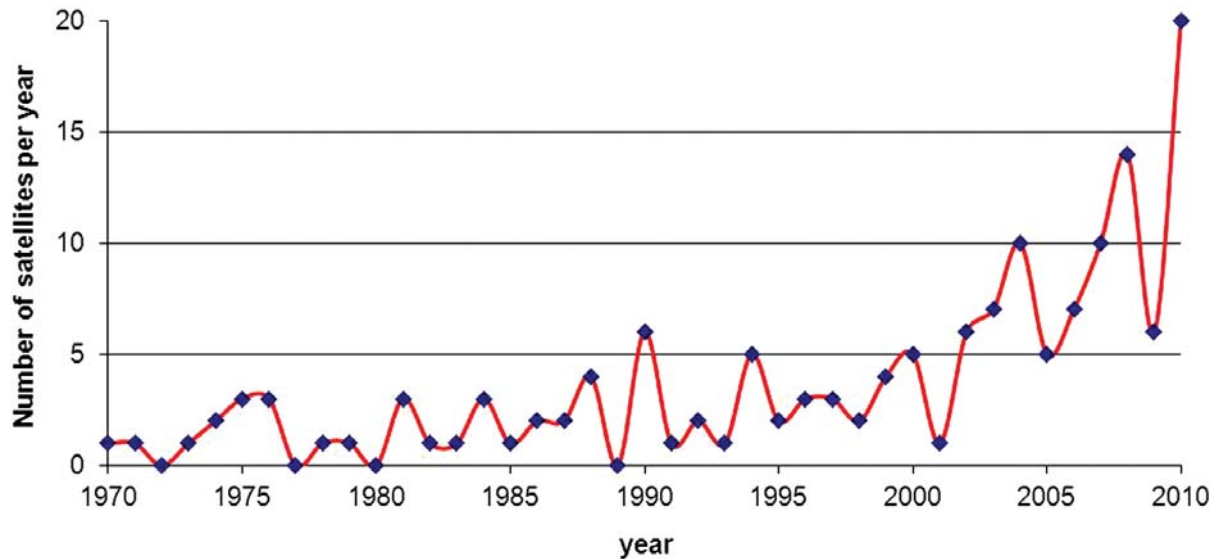
Figure 5: China Satellite Launches Cumulative 1970-2010
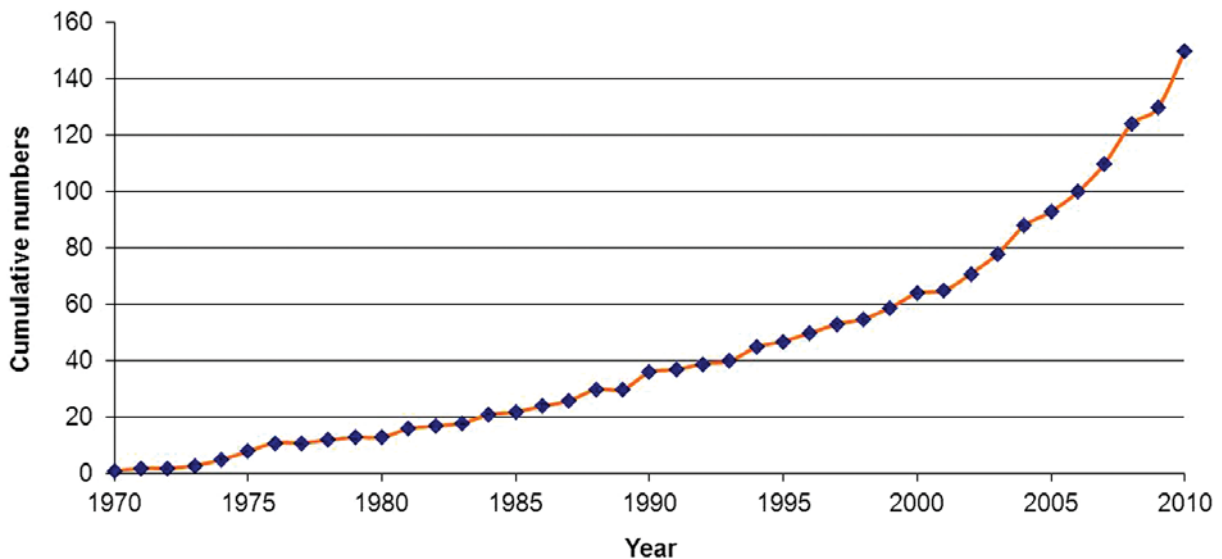
[10] Annual Report To Congress, "Military and Security Developments Involving the People's Republic of China-2010", http://www.defense.gov/pubs/pdfs/2010_CMPR_Final.pdf p. 37 - "Over the long term, improvements in China's C4ISR, including space-based and over-the-horizon sensors, could enable Beijing to identify, track, and target military activities deep into the western Pacific Ocean." p.47 - "Specifically, China's defense industries are pursuing advanced manufacturing, information technology, and defense technologies. Examples include radar, counter-space capabilities, secure C4ISR, smart materials, and low-observable technologies."

Figure 6: Number of Satellite Launch Vehicles per Year Chine 1970-2010
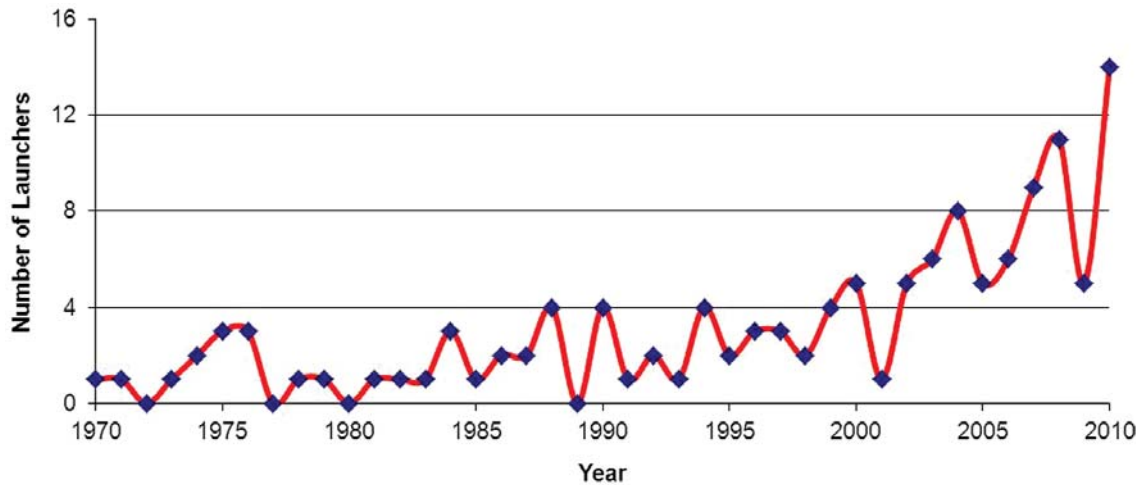
Figure 7: Number of Satellite Launch Vehicles - China Cumulative 1970-2010
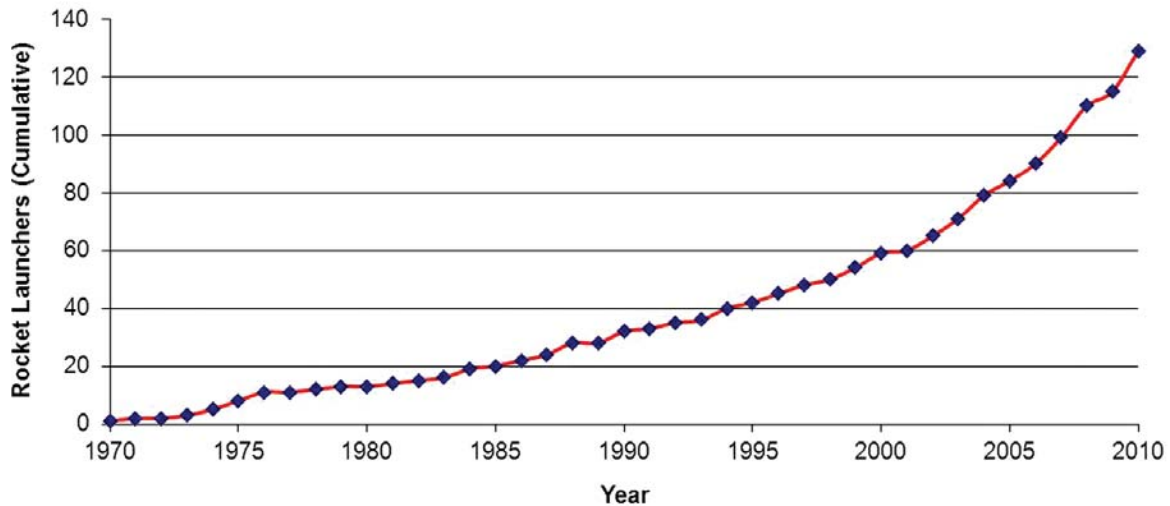
PART II
DF-21 ANTI-SHIP BALLISTIC MISSILE

5.1 Analysis of Maneuver Requirements

This analysis is based on earlier work by the National Institute of Advanced Studies (NIAS) on Chinese Ballistic Missiles.[11] The DF-21 ballistic missile is a variant of the Chinese JL-1 Submarine Launched Ballistic Missile. Based on available pictures of the JL-1 we had worked out suitable procedures for determining the relevant missile parameters. We had also developed a trajectory model for determining the range. The advanced version of this trajectory model includes not only estimating the maximum range of a missile fired
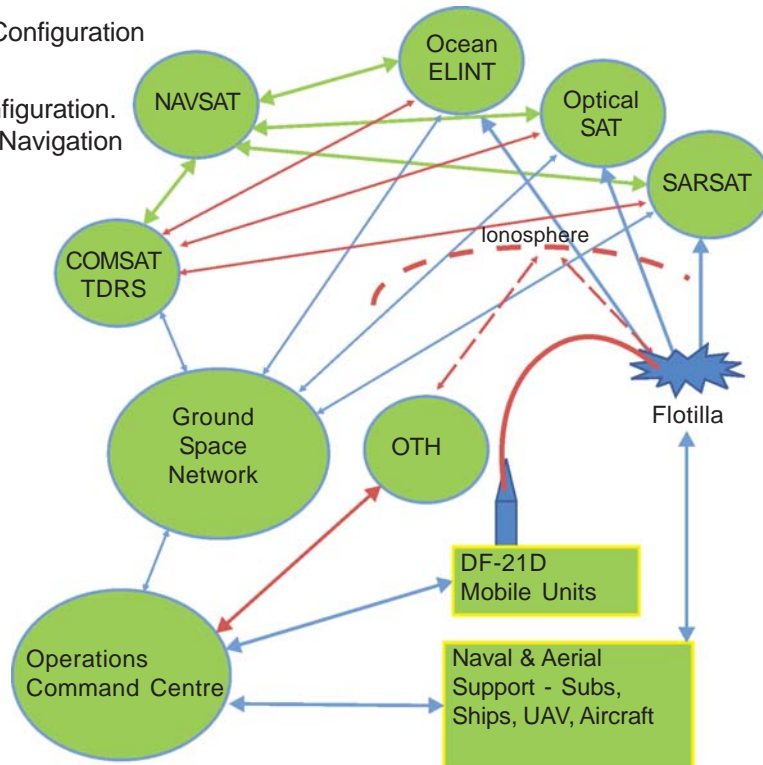
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[11] S. Chandrashekar et al, "An Assessment of China's Ballistic and Cruise Missiles", NIAS Study Report R4-07, 2007.

Figure 8:

ASBM - Operational Configuration

Significant Space configuration. SAR, Optical Recon, Navigation Communication exist

Civilian Programmes Manage Space Well- multiple reception of data

Large Area Ocean ELINT

OTH - addl. input

Integration of all components

Ocean ELINT

NAVSAT

Optical SAT

SARSAT

Ionosphere

COMSAT TDRS

Ground Space Network

OTH

Flotilla

DF-21D Mobile Units

Operations Command Centre

Naval & Aerial Support - Subs, Ships, UAV, Aircraft

Source: Erickson & Yang

in any direction but also provides trajectories needed for going from a point A to a point B.

Most pictures of the DF-21 available in the public domain show the missiles inside a canister, making it difficult to estimate the lengths and diameters of this missile accurately. In the present analysis we have used our best estimates of propellant and stage masses that we had obtained from available pictures of the JL-1. Our earlier analysis had included a payload mass of 700 kg as the mass of the nuclear warhead of the JL-1 missile.[12]

The ASBM differs fundamentally from the other missiles in the DF21 series in that it carries a

conventional and not a nuclear weapon. This has significant implications.

To cause any damage to the target the warhead will have to directly impact on the carrier. This would only be possible through the addition of a terminal self-guidance capability. Such a missile also requires a Maneuvering Reentry Vehicle (MaRV) with a radar, an on board computer and a system of thrusters as well as control surfaces.

For an ASBM role, a conventional warhead would have to be specifically designed to penetrate and cause severe damage to the carrier with its reinforced flight deck. An alternative solution is

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[12] See Reference 11, pp. 36-37.

to rely on sub-munitions designed to spread lighter but widespread damage to aircraft on deck, the flight deck equipment and upper deck electronics thereby achieving a "soft kill". Such an approach does not need deck penetration. This option would also have the advantage of reducing the criticality of pin-point accuracy.[13] Our calculations are however based on the higher mass "deck penetration" payload as the intention is to analyse the viability of the concept using conservative assumptions.

As a starting point for the current analysis of the DF-21 in its anti-ship task we assume that this mass of the MaRV would be about 1200 kg.[14] The additional mass of 500 kg would be required for replacing the nuclear warhead with a conventional high explosive warhead that can penetrate a carrier's reinforced hull. Additional sensors such as an on-board radar and propulsion capabilities for terminal maneuvers of the missile are also needed. The starting assumption is that all of these can be accommodated within the 1200 kg payload.

5.2   Assumptions

♦   Propellant weight of first stage   7686 kg
♦   Inert mass of stage 1   1574 kg
♦   Propellant mass of stage 2   4209 kg
♦   Inert mass stage 2   467 kg
♦   Warhead with all ASBM   1200 kg
    capabilities

♦   The burn time assumed for stage 1 and stage 2 (both solid propellant) is 70 seconds each.

♦   The vacuum specific impulse assumed for both stages is 280 seconds.

♦   Corrections for the change in specific impulse with altitude have been incorporated in the model.

♦   Drag corrections that vary with height and air density and velocity of the missile are also included.

♦   The model also takes care of earth rotation effects.

♦   The launch site is located at 23 degrees 48 minutes. N latitude and 113 degrees 6 minutes E Longitude (around Qinyuan in Guangdong province).

♦   The initial target location is 19 degrees N Latitude and 131 degrees 42 minutes E Longitude (ENE of Manila, Philippines).

♦   The range of the target from the launch site for the above coordinates of launch station and target is 1996 km.

♦   Launch azimuth would be east-south-east from the launch location approximately 102 degrees Azimuth). The maximum range at this azimuth would be 2007 km for the 1200 kg payload. This is close to the 2000 km range of the ASBM mentioned in various publications. We can see that the target distance from the launch station is 1996 km which is very close to the maximum range of 2007 km for the JL 1 / DF 21 unmodified missile with a payload of 1200 kg.

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[13]   A recent intelligence analysis published in the United States casts doubt on the future development plans of antiballistic missile defence systems in the United States and Israel, and calls for a reassessment of the policymakers' basic premises. The intelligence analysis states that within a few years, China and North Korea will be able to develop ballistic missiles with blast fragmentation warheads containing some 100 sub-munitions (similar to bomblet-filled cluster bombs), weighing about 5 kg each. [FBIS Translated Text] http://www.fas.org/news/israel/nes95199.htm

[14]   Public domain information suggests that the range of the ASBM is about 2000 km. The 1200 kg payload was used as a starting baseline because it provides a range of a little over 2000 km to an unmodified JL-1 / DF-21 missile.

This makes it a very convenient and appropriate starting point for our analysis. (See Figure 9)

5.3 The Problem to be evaluated

During the descent phase of the missile's ballistic trajectory it obtains a better fix on the location of the target. The revised target location would be within the radius of uncertainty, comprising mainly the error in the radar range and bearing, as well as the motion of the target during the missile's time of flight. Assuming an OTH radar error of 20kms, and a distance of 15kms traversed by the target during the time of flight of the missile, the radius of uncertainty works out to be 25kms.[15] The missile has then to execute a maneuver during its flight which will enable it to hit the target.

In principle the maneuver could be carried out at any altitude. The velocity correction required

Figure 9:

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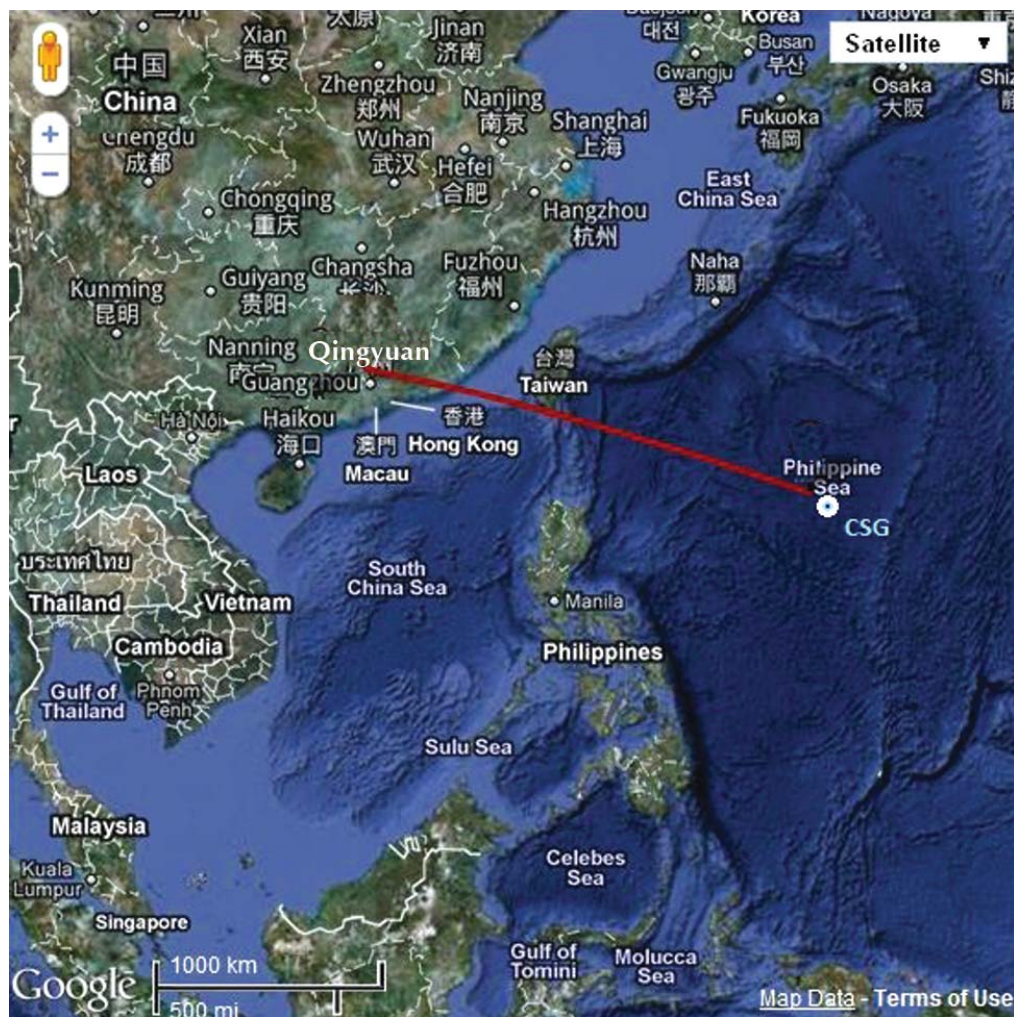
[15] The Root mean square of the two errors from the OTH and the motion of the ship during the flight time of the missile is taken as the final error.

to hit the target in its updated position will depend on the velocity of the missile at that point. The velocity in turn depends on the altitude and increases as the missile comes closer to its original impact point. So if the maneuver is carried out early in the descent phase the velocity correction and the requirement of fuel that will have to be carried on the missile will be less. If it is carried out later during the descent phase the velocity correction and the fuel requirement are both likely to increase.

The velocity correction would take some time – of the order of a few seconds – during which the missile is also moving. This aspect has also to be considered. Once the missile comes to an altitude below 75 km, aerodynamic drag and heating become high. The functioning of the radar on the missile may experience some problems during some part of the re-entry phase because of ionization. If further maneuvers are required, the missile will also need to be equipped with aerodynamic control surfaces for stability and maneuverability. It may also require to be slowed down by using retro rockets for the aerodynamic surfaces to be effective. There may also not be much time for the missile to fully execute major maneuvers at altitudes below 75 km before it reaches the point of impact. These are additional aspects that require more specialist investigations.

One of the constraints that will determine the time at which the maneuver should be carried out will be the detection range of the radar on board the missile. The weight and the power requirements for such radars are likely to increase depending on this range. **Extrapolating from airborne radars our estimate of the range of a typical radar system that can be accommodated within the weight and power budgets of the missile would be 300 km.** Our analysis will try to evaluate the velocity corrections that are needed at different altitudes and at different ranges from the updated target locations. Keeping in mind the constraints of the radar system we will try to identify the range of altitudes and velocities around which the maneuver can be carried out. From these considerations we will try and estimate the amount of propellant required to carry out the maneuver.

There are two ballistic trajectories available to go from Point A to Point B. The shallow trajectory may in general be preferred for tactical considerations. If the target is close to the maximum range as it is in our starting case there may not be any significant difference between the lofted and shallow trajectories.

5.4 Results of Baseline DF-21 Case

As we would expect when the range of the target is very close to the maximum range of the missile (2007 km maximum range – 1996 range of target) there are no major differences between the lofted and shallow trajectories

Selected data obtained from our trajectory programme for the DF 21 unmodified missile for the specified target is provided in Table 2 below. The maximum values of slant range and velocity corrections that are needed to go from the initial target point to a revised target point that is located around a radius of 25 km (the Area of Uncertainty) from the initial target point are taken for preparing this Table.

The maximum altitude that the missile reaches is 493 km. The geometry of our test case is such that the slant range requirements from the onboard radar dictate that the maneuver be carried out at an altitude of between 200 km and 150 km. The incremental velocity needed to carry out the maneuver would be about 400 m per second.[16]

The propellant required for such a maneuver would be about 150 kg. This would mean that the warhead, the on-board radar, re-entry shielding, aerodynamic control surfaces, navigation and control components as well as the propulsion tank should all come within an overall weight of about 950 kg.

5.5 Impact of the Reentry Vehicle size on the DF-21 missile – the DF-21D Variant

The parallel studies on the Re-entry Vehicle **(See Annexure 2)** indicate that in order to accommodate the high impact warhead, an autonomous radar-based navigation system, the propellant and the power plant required to maneuver the re-entry vehicle at altitudes of 200 to 100 km and the aerodynamic surfaces required for maneuvers below 50 km, the weight of the re-entry vehicle would be about

1700 kg. This mass is about 500 kg more than the mass of 1200 kg that we had assumed for the re-entry vehicle earlier. We assume that the re-entry vehicle mass would be about 1700 kg rather than the 1200 kg we had assumed in our first iteration. **Annexure 2** provides some details of how this mass requirement was worked out.

To be able to launch this payload to a range of over 2000 km – as is being proposed by the Chinese – significant changes have to be made to the DF-21 missile. The results of our preliminary studies on these changes and their implications are presented below.

When we replace the 1200 kg payload with a 1700 kg payload the maximum range for our baseline DF-21 missile for a launch azimuth of about 102 degrees is about 1381 km. This is significantly lower than the 2000 km range talked about in publicly available information on the ASBM. In order to reach the 2000 km range with some margins the DF-21 missile has therefore to be modified. There are various ways in which this missile can be modified. One approach could be to add a small third stage to the DF-21. Another way is to incorporate a liquid engine module in the RV. This option would be

Table 2: RESULTS BASELINE JL-1 / DF-21 CASE
Velocity Changes for 25 km Error in Position Lofted / Shallow Trajectory – DF-21 1200 kg Warhead

Time of Maneuver From Launch (sec)	Maneuver Altitude (km)	Slant Range to Revised Target (km)	Velocity increment (metres/sec)	Total Flight Time (sec)	Time from maneuver to impact (sec)	Velocity at maneuver
758	200	337	300	839	81	3.58
780	150	256	410	839	59	3.70
802	100	175	639	839	37	3.83
812	75	135	851	839	27	3.89

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[16] As we can see from the Table the estimated values are between 300 and 410 metres per second.

equivalent to using the warhead itself as a third stage.

These options were studied. However the preliminary analyses of these options indicate that the additional weight that has to be carried by the missile at lift-off reduces the range below 2000 km. Therefore these options of adding a third stage or converting the warhead into a 3rd stage do not look attractive from a technical point of view. **It is therefore likely that the first and second stages of the existing DF-21 missile would have been modified to provide the increase in range for launching a 1700 kg warhead.** Different combinations of extended first and second stages of the baseline DF-21 were analysed to come up with a configuration that would be able to carry a payload of 1700 kg to a range of a little over 2000 km. Table 3 provides details of a missile that provides a range of 2232 km.

The configuration above can be arrived at from the basic DF-21 missile by adding 3000 kg of propellant to its first stage and about 1400 kg of propellant to its second stage rocket motor. The addition of this propellant will increase the length of the first stage rocket motor of the DF-21 from a value of 4.3 m to 6 m. The length of the second stage rocket motor will also increase from 1.5 m to 2 m.

5.6   Maneuver Requirements Revisited

Based on the above sizing of the DF-21D the maneuver requirements for the warhead have been evaluated again. As mentioned earlier the maximum range that can be achieved by such a missile launched at an azimuth of about 102 degrees is 2232 km. Using the same launch site location and the same target that we had used earlier we have re-run the trajectory keeping the initial position of the target at the same location[17] but maneuvering the missile during flight to hit the revised target position which lies within a 25 km radius of uncertainty. The relevant details from these trajectory runs are presented in **Table 4** for the shallow trajectory case and **Table 5** for the lofted trajectory case.

Table 3: Possible Configuration of DF-21 D ASBM Missile

Parameter	Value
Mass of Propellant first stage motor (Kg)	10686 Kg
Inert Mass of first stage (Kg)	2188 Kg
Vacuum specific impulse first stage (Sec)	280 seconds
Mass of propellant second stage motor (Kg)	5609 Kg
Inert Mass of second stage (Kg)	622 Kg
Vacuum specific impulse second stage (Sec)	280 seconds
Payload mass (Kg)	1700 Kg
Lift off Weight Kg	20806 Kg
Range for azimuth of 102 degrees (Km)	2232 Km
Estimated length of 1st stage rocket motor	6 m
Estimated length of second stage	2.25 m

[17]   The range from the launch site to the target is about 1996 km.

For the shallow trajectory case, a maneuver at 100 km altitude meets the range limit of 300 km required by the radar onboard the missile. The additional velocity required to carry out the maneuver to hit the target works out to be 400 metres per second. Assuming that a velocity correction of about 425 metres per sec is needed the propellant required for the maneuver of a 1700 kg warhead would be about 230 kg. This would still provide a mass of more than 1450 kg to accommodate all the other requirements of the warhead. The maximum altitude reached by the shallow trajectory is 247 km.

A maneuver carried out at an altitude of 200 km would require a velocity correction of about 371 m per sec for the lofted trajectory case. This is not significantly different from the shallow trajectory case though the maneuver can start at higher altitude of above 200 km. The maximum altitude reached for the lofted trajectory is 690 km. The

time available between maneuver and impact are also approximately the same for both the lofted and shallow trajectory cases - 62 to 65 seconds.

From the analyses of these two cases we can conclude that a velocity correction of 425 metres per second would suffice for both the lofted and shallow trajectory cases.

5.7   DF 21D Image Measurement Substantiate Analysis

The parameters in Table 3 of the modifications visualized to the DF-21D ASBM are derived from knowledge about the parameters of the earlier DF-21 missile variants based on image analysis supplemented by other information available in the public domain. One way to evaluate the correctness of our analysis for the DF-21D is to validate our findings by checking our conclusions with independent measurements made on

Table 4: Velocity Changes for 25 km Error in Position
Shallow Trajectory - DF-21D 1700 kg Warhead

Time of Maneuver From Launch (sec)	Maneuver Altitude (km)	Slant Range to Revised Target (km)	Velocity increment (metres/sec)	Total Flight Time (sec)	Time from maneuver to impact (sec)	Velocity at maneuver
483	200	649	163	637	154	3.86
535	150	445	246	637	102	3.98
575	100	285	400	637	62	4.10
592	75	213	554	637	45	4.16

Table 5: Velocity Changes for 25 km Error in Position
Lofted Trajectory - DF-21D 1700 kg Warhead

Time of Maneuver From Launch (sec)	Maneuver Altitude (km)	Slant Range to Revised Target (km)	Velocity increment (metres/sec)	Total Flight Time (sec)	Time from maneuver to impact (sec)	Velocity at maneuver
909	200	284	371	974	65	3.72
928	150	212	511	974	46	3.85
944	100	148	771	974	30	3.97
953	75	116	1041	974	21	4.03

images available in the public domain. A search for images of the DF-21D provided one very good image **(Fig.10)** of a number of missiles mounted on their Transportable Erector Launcher (TEL) vehicles.[18] Since these TEL vehicles are derived from the Russian MAZ TELs with known dimensions [19] they can be used to determine the lengths of the various parts of the DF-21D missile, especially the lengths of the rocket motors of the first and second stages.

The measurements derived from the above image are provided in Table 6 below. The Table also provides the average measurements as well as the original measurements on images of the earlier variants of the DF-21 missile from the best image measurements that have been made at NIAS.[20]

The measured length of the DF-21D variant of 13.34 m is longer than the lengths of the various variants of the DF 21 that we had seen earlier.

As per our calculations (see Table 3) to accommodate the ASBM payload of 1700 kg and to be able to reach a range of 2000 km both the first and second stages of the earlier unmodified JL 1 / DF 21 missile had to be stretched by adding more propellants to both of them. Since the diameter for both the original DF21 and the ASBM variant is the same, the addition of propellant will increase the length of the first stage from 4.3 m in the earlier version to 6 m in the ASBM DF 21D variant. From Table 6 the measured length of 6.10 m for the first stage motor is only 10 cm more than the length of 6 m that we had arrived at by calculation. Thus the

Figure10:

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[18]   For a copy of the image see http://www.china-defense-mashup.com/wp-content/uploads/2010/12/anti-carrier-missile.jpg

[19]   The MAZ TEL Soviet heritage TEL has a distance of 2.2 m between the centres of two wheels. The Chinese TELs are derived from this MAZ TEL. 2.2 m has been used as the benchmark length for our measurements on the image

[20]   Reference 11 pp. 36-37

Table 6: Comparison of Measurements between DF-21D & JL-1 / DF-21 Variants

Parameter	Earlier Values	DF 21 D Measured value	Comment
Warhead + Interface	2.3 m, 3.21 m, 3.7 m & 5.13 m	3.21 m	4 types of warheads seen earlier. DF-21D variant close to one of them.
Upper stage + Interface	1.79 m (average)	2.25 m	Upper stage length longer by about 0.5 m consistent with increase in propellant loading of stage 2 from calculation.
Stage 1 Motor	4.3 m (Average)	6.10 m	Stage 1 rocket motor longer by about 1.8 m in DF-21D. Consistent with increase in length of 1.7 m obtained from calculation.
Nozzle / shroud	0.89 m (average)	1.78 m	Not inconsistent with DF-21D
Length	9.3, 10.2, 10.7 and 12.1 m - 4 variants.	13.34 m	The DF-21D is a longer variant that is consistent with a range of 2000 km + with a 1700 kg payload.

measurement from the image is quite consistent with our calculation for the first stage rocket motor of the DF 21D variant.

In the same way the upper stage lengths of the DF 21 D ASBM variant is quite close to the value (difference of 5 cm) we obtained from our calculations. This is seen in Table 6.

Measurements from the image of the DF-21D are therefore very consistent with our calculation of lengths based on our approach to the problem of the ASBM. The real DF 21D as seen in the image appears to be close to what we would expect if the earlier version of the DF 21 has been modified for the ASBM function.

The warhead + interface length of 3.21 m has been seen in earlier versions of the DF-21. However while the length may have been the same the layout and arrangement of the DF-21D warhead appears to be different. The image of the earlier variant of the DF-21 which had a measured warhead + interface length of 3.21 m reproduced below **(Fig.11)** has a significantly

different warhead. **Annexure 2** provides some details about the warhead based on our investigations so far.

Overall the DF-21D appears to be a missile that is significantly different from all earlier variants of the DF-21. Based on this work we can make certain predictions about the DF 21D variant of the D 21 missile.

5.8 Tentative Predictions about the DF-21D Missile

- Missile diameter 1.4 m
- Overall length of the missile about 13.5 m
- Overall weight of the missile ~21 tonnes
- First stage motor length a little over 6 m
- First stage propellant mass about 10700 kg
- Second stage length including nozzle about 2.25 m
- Second stage propellant mass about 5600 kg
- Range with a payload of 1700 kg about 2200 km

Figure11:

- Total flight time of about 640 seconds for shallow and about 980 seconds for the lofted trajectory case.[21]

- The warhead must have a high thrust capability engine system that provides a quick correction to the missile velocity. The dynamics of this correction and its implications need more investigation.

5.9 Conventional Warhead – Effect on Missile Design Options

Accuracy

A missile with a conventional warhead needs to be far more accurate than a nuclear-tipped weapon for obvious reasons. It is difficult to strike a moving target from a range of over 2000 kms. This is only possible if there is terminal guidance from either internal or external data inputs. Last minute updates are necessary because of the errors in each component of the ASBM system –

the OTH radar, the errors accumulated during flight of the missile, and the errors caused by the movement of the target. The requirement of data input can be met from a global positioning system and /or by an on-board radar.

The mean CEP of a medium range ballistic missile in unguided flight is 250-300m. This can be improved dramatically as shown by the US modifications to the Pershing and the USSR's SS-20 missile.

The CEP of the ASBM is therefore of crucial importance. In order to strike the target (a) the CEP of the ASBM would have to be half the beam or less. (b) The onboard computer should be steering the missile at the future position of the target based on updates during the terminal stage.

It would be useful to recall that the US Pershing Mark II reportedly had a CEP of 50 meters in

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21   One of the articles quoted in the literature talks of a flight time of 930 seconds – could be a reference to the lofted trajectory case. Our analysis does not suggest any major differences in terms of maneuver requirements between the lofted and shallow trajectories. The time interval between maneuver and impact is also not very different. From a tactical perspective a shallow trajectory may be preferred.

1987[22]. In 2003, the US Navy had requested for funding for the E2 RV with a conventional warhead for the Trident II D SLBM, with an accuracy of 10 meters. This was after Lockheed Martin had demonstrated the previous year that the new reentry vehicle could steer towards a target and strike with improved accuracy.[23]

There are clear indications that China has been working on enhancing the accuracy of its missiles starting with the DF-15, which without any guidance has a CEP of around 300 meters. This is similar to the early unguided Pershing, which was improved as stated above to 50m over a few years. In 1996 the Wall Street Journal published a report by an analyst quoting an engineer from the Beijing Research Institute for Telemetry that China was enhancing the accuracy of the DF-15 with global positioning satellite technology, and stated that with guidance from a GPS the D-15 could "perhaps become the most accurate battlefield missile in the world."[24] This of course is a dated report and therefore things could have only gotten better. China has by all accounts made impressive strides in technology in the last decade and a half since that assessment. Considering that the accuracy of 10m was projected by the US for an ICBM of over 7000 km range in 2003, the possibility of

a similar MaRv being built by China for a 2000 km MRBM is entirely feasible, even allowing for the technology lag that China has in relation to the US.

Nature of Munitions

Notwithstanding all efforts to attain pin-point accuracy, and even allowing for salvo firings of the ASBM, the "soft kill" option is an attractive one against a target as robust and as damage-resistant as an aircraft carrier. The adoption of the "soft kill" option, (the disablement of the mission capability of the warship rather than its actual damage or destruction as with conventional munitions) has distinct advantages. In this option the unitary warhead is replaced by a warhead which ejects up to a thousand sub-munitions (bomblets) over a wide area, causing severe damage to soft targets such as aircraft on deck, unarmoured vehicles such as flight-deck tenders, and weather-deck radio and electronic equipment, masts and antennae. This kind of damage would certainly make a carrier incapable of its primary function and put it out of action. Sub-munition warheads reduce the mass of explosive needed to be carried by the missile. They also simplify the design of the warhead which would otherwise have to have the capability to penetrate the thick steel and

[22] http://www.fas.org/spp/aircraft/part04.htm

[23] Grossman, Elaine M, "Pentagon Eyes Bunker-Busting Conventional Ballistic Missile for Subs," *Inside the Pentagon*, June 27, 2002.p. 1. See also, Robert S. Norris and Hans M.Kristensen, "U.S. Nuclear Forces 2005," *Bulletin of the Atomic Scientists*, January/February 2005, pp. 73-75.

[24] Richard D. Fisher Jr., "China's Missile Threat" Wall Street Journal 30 Dec 1997 http://www.fas.org/news/china/1996/msg00039b.htm "China is working hard to improve the accuracy of its missiles. At November air show in Zhuhai, China, an engineer from the Beijing Research Institute for Telemetry, an organization working on advanced guidance systems, told this analyst that China is enhancing the accuracy of the DF-15 with global positioning satellite technology. The U.S. already relies heavily on such technology to convey pinpoint accuracy to aircraft, missiles and bombs. Published estimates give the DF-15 an accuracy measured in a "circular error probability" of 300 meters, or within a circle with a 300-meter radius. This figure is already fairly accurate by current standards for this class of missile. With global positioning satellite inputs, the DF-15 could perhaps become the most accurate battlefield missile in the world."

concrete flight deck.[25] Finally, the soft kill option would be less likely to invite escalation that the loss of an aircraft carrier - the symbol of US might-might evoke.

5.10 Other Considerations

In our analyses we have assumed that the velocity corrections are carried out instantaneously. In actual practice the velocity correction would take some time – of the order of a few seconds – during which the missile is also moving. With thrusters that can provide about 7500 Newtons of thrust and having two of them in any direction about 15000 Newtons of thrust may be available every second. For the maneuver a minimum of eight of them located in the positive and negative pitch and yaw planes may be needed. From these considerations it would appear that the maneuver would take about 10 seconds. If the thruster is made bigger this time can come down. This aspect and the dynamics of motion during the thrusting phase have to be modeled and understood.

Once the missile comes to an altitude below 75 km, aerodynamic drag and heating become high. The functioning of the radar on the missile may experience some problems during some part of the re-entry phase because of the formation of an ionized plasma sheath around the missile that affects radio waves. Our preliminary evaluation is that for typical speeds of reentry for the DF 21 D of around 4 km per second this may not be a major problem. Radio frequencies below about 285 MHz might not be seriously affected. In case higher frequencies have to be used there are a number of technical solutions that can be used. For a 4 km per second reentry velocity even this may not be needed.

If further maneuvers are required, after the missile comes below 75 km, the missile will also need to be equipped with aerodynamic control surfaces for stability and maneuverability. It may also require to be slowed down by using retro rockets for the aerodynamic surfaces to be effective. There may also not be much time for the missile to fully execute major maneuvers at altitudes below 75 km before it reaches the point of impact.

All these are additional aspects that require more specialist investigations.

5.11 Summary of Analysis of Missile Requirement

Evaluation of the older variants of the DF 21 led to the conclusion that they were not compatible with the performance characteristics needed for the ASBM. The DF 21 needs to be significantly modified for it to attain the enhanced performance parameters required for an ASBM. Onboard radar, terminal maneuvering equipment and an increase in the mass of explosive are needed for the ASBM function. The increased mass and dimension of the Re-entry Vehicle and the fuel requirement were independently evaluated. This input was used to arrive at a revised 2 stage variant of the original baseline DF 21 missile. Revised trajectory runs on this variant provided more refined inputs that confirmed that the performance parameters could be achieved.

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[25] http://www.rand.org/content/dam/rand/pubs/monograph_reports/MR1028/MR1028.sum.pdf "An 1,100-pound M-9 ballistic-missile warhead covers almost eight times the area when using a submunition warhead than when using a unitary warhead. The *combination* of increased accuracy from GPS guidance and increased warhead efficiency is what decreases the number of missiles required to attack USAF airbases from hundreds to dozens."

To cross-check the validity of the theoretical modifications, we compared the external dimensional characteristics of the two stages of the missile derived from our calculations with measurements made on a picture of the ASBM (DF 21 D) that was available. We found that there was close correspondence between the dimensions derived from our calculations and the measurements made on the image. This confirms that the DF 21D is a real variant of the DF 21 family of missiles that can indeed perform an ASBM function.

Our analysis leads to the conclusion that the DF-21D missile is capable of the performance it is credited with in terms of range and payload. With onboard radar and the addition of control surfaces the missile will acquire terminal self-guidance and velocity correction capability. Such a reentry vehicle can achieve the required "Circular Error Probable" that would give it a high hit probability. In addition the use of sub-munitions would diminish the stringency of the CEP requirement and also give the missile a "soft kill" capability. These parameters need to demonstrated during the trials which are yet to be carried out, in order to establish the credibility of the missile as a viable anti-ship weapon.

PART III
STRATEGIC IMPLICATIONS

The development of the Anti-Ship Ballistic Missile (ASBM) by China has been known for a number of years. However, real concern in the US and the Pacific region began to manifest itself in 2009, after several broadcasts in the Chinese media talked about the new counter to the US Navy's aircraft carrier. The most authoritative publicly expressed view was provided in December 2010 when the C-in-C US Pacific Command stated in an interview that in his view China's ASBM had attained Initial Operational Capability, and that it would probably take a few years more of trials before the missile becomes fully operational. In this part we examine some strategic causes and effects of the development of an Anti-Ship Ballistic Missile by China. **Annexure 3** provides a Chinese perspective on how an ASBM would be used operationally to counter the threat posed by CSGs.

Chinese Perspective

It would be an over-simplification to suppose that objective of re-absorption of Taiwan into China was the main driver of the ASBM development programme. While this was no doubt a factor, the ASBM's impact on maritime strategy and operations go far beyond the bounds of a littoral conflict. The successful deployment of the ASBM by China would impact geo-political equations not only in the Western Pacific but globally – so central is the carrier to America's power projection capability.

China's resort to a land-based long-range weapon against American sea power appears to be a logical choice. China could never have hoped to match the US Navy at sea, or withstand sustained air strikes by its formidable carrier-borne aircraft. It has adroitly avoided both these weaknesses and produced an "assassin's mace" solution. In the near term, the ASBM when it attains full operational status will serve as a credible deterrent against American intervention in China's maritime disputes, of which it has several with its Asian neighbours.

Being a conventional weapon, the ASBM for the first time gives China the capability of a graduated response to the CSG threat. If sub-munitions which do not aim to destroy the carrier but only to disable it are used, it further increases the graded response capability. China can then claim that the ASBM is a defensive weapon that minimises the chance of escalation of the conflict.

US and Allied Perspective

Opinions about the viability of the weapon and its impact on the maritime and geo-political situation range from scepticism to alarm. To a large extent, the scepticism has centred around China's technological capability. But as the US Admiral has said, China's capabilities and rate of progress have always been higher than they have been credited with.

To counter the developing ASBM threat the US has taken a number of steps. For the most part these consist of redeployment of existing assets to strengthen the Pacific Fleet, especially in the area of missile defence. The US already has a program for increasing the number of BMD-capable ships from 18 in 2009 to 43 in 2020[26]. This is in accordance with the decisions taken before the ASBM threat appeared on the horizon, which is sought to be met by re-deploying these BMD assets.

From the measures that have already been taken it is clear that the defence against the missile will be enormously expensive, nor will it be fail-safe. The US Navy can no longer dispatch its CSGs without a careful appraisal of the risks involved. Additional defensive measures such as Aegis-capable escorts will push the costs up by several hundred billion dollars to meet a threat that costs a fraction of that amount. In an article published by the US Naval War College Review last year, Marshall Hoyler has made a detailed estimate of the equation between the anti-missile defence capability of the US Pacific Fleet versus China's ASBMs, and concludes that with the projected deployable assets on both sides, this would leave the balance of numerical advantage heavily in favour of China till 2015.[27]

The situation will also increase nervousness among US allies in Asia, who are already apprehensive about China's growing power. There is the possibility that China will become more belligerent in the resolution of its disputes, and that its "peaceful rise" will be less peaceful.

Implications for Maritime Strategy

Current naval strategy recognizes that for a maritime power to be able to operate at will in distant waters it needs integral air power, and the aircraft carrier is central to that precept. The advent of the ASBM does not in any way dilute this principle. But what it does do is to complicate the task of keeping that air power integral with the fleet. Future carrier strike groups may consist not of one super-carrier with many escorts, but several small carriers with many of the escorts' capabilities. A land-based weapon

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[26] Ronald O'Rourke, "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress" Congressional Research Service Report – Jun 23rd 2011

[27] Marshall Hoyler, "China's "Antiaccess" Ballistic Missiles And U.S. Active Defense 2010" Naval War College Review, Autumn 2010, Vol. 63, No. 4.

may be able to achieve sea *denial* over some part of the sea for a certain time, but it cannot give a country sea *control*. For a country to maintain sea control, (to be able to use the sea as well as to deny it to the adversary) it needs sea-based platforms. Thus the very strength that China is acquiring may also expose its own weakness. This is because the trajectory of China's development and its westward economic expansion makes it more dependent on parts of the world ocean over which it has no control, and over which control can only be achieved by building a fleet with its integral air power.

Implications for Nuclear Stability

The response to a detected incoming ballistic missile would be the most difficult problem for a commander at sea in an operational environment involving both nuclear as well as conventionally-tipped ballistic missiles. In the case of an incoming missile being reported, the commander of the carrier will only have seconds to decide whether he is under a nuclear attack and to take appropriate action. This obviously makes for a high-risk situation with an increased probability of a nuclear response to a conventional attack. The US discovered exactly the same issue in 2005 when the Air Force and the Navy both proposed the deployment of long range ballistic missiles with conventional warheads. Whereas the military did outline some measures that they said would obviate the risk, a Congressional Research Service report acknowledged that the risk of a conventional ballistic missile launch being presumed to be a nuclear attack was real.[28]

The deployment of the ASBM will be met by intensification of BMD measures by the US and its regional allies. China has protested strenuously against Theatre Missile Defence plans in its region as it considers that this will dilute the value of its own strategic deterrent.

Another effect of the development of the ASBM has been to renew Russia's misgivings about the INF treaty of 1987, whereby the US and the USSR both voluntarily eliminated all intermediate range missiles, and now have no missiles in the range bracket of 500-5500 kms. It is likely that Russia will withdraw from the Treaty and feel compelled to arm itself with IRBMs. This could start another round in the presently discontinued missile competition. The deployment of the ASBM will thus have an overall negative impact on nuclear stability and may lead to an accelerated arms procurement programme on all sides.

Possible Countermeasures

Essentially the countermeasures against such a weapon fall into one of two categories – active and passive.

Active countermeasures can be aimed at the surveillance and tracking systems, the missile launch systems, or the missile arsenals. This would include the disablement of the OTH radars, or the tracking and communication satellites system by jamming or other means. Missile launch and missile arsenals may be subjected to neutralisation from the air which is a course of action fraught with high political risk

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[28] Amy F Wolf Specialist in Nuclear Weapon Policy, "Conventional Warheads for Long-range Ballistic Missiles – Issues for Congress" Congressional Research Service Paper Jan 26 2009.

and presents military difficulties. Long-distance precision guided weapons are the most likely option.

Passive countermeasures are countermeasures that are taken after missile launch to destroy, decoy or evade the missile. The acquisition of Anti Missile Defence (AMD) systems involves enormous expenditure; but the US has already planned to strengthen its AMD in cooperation with its regional allies, and this expenditure has already been planned for the 20-year period starting in 2010, after the last Ballistic Missile Defence (BMD) Review by the US President. It is therefore unlikely that the US will rely purely on passive means as this would leave all the initiative with the adversary, and also involve the risk of AMD systems being overwhelmed by sheer numbers since they are spread thin among the various assets that have to be defended.

Either way there are no easy options. There is little doubt that there will be intense diplomatic activity to avoid actual confrontation. China is not likely to make the mistake of assuming that US Carriers would stay away from the Western Pacific because of the ASBM.

PART IV CONCLUSION

This study has examined China's capability to design and develop an Anti-Ship Ballistic Missile directed against an Aircraft Carrier Strike Group (CSG), and to create the technical infrastructure to transform this into an operational weapon system.

It is clear from the study that over the last decade China has intensified efforts to create a

constellation of satellites with the necessary attributes and sensors to provide all-weather data about ships over a wide ocean area. These include infra-red, synthetic aperture radar, and optical sensors with the necessary earth links to transmit data to operational authorities. It also includes a new large area ocean ELINT satellite launched in May 2010 that would provide advance warning of the arrival of a CSG and its location. While this system may not yet be complete, there is enough indication that it has reached an advanced stage. This may be the reason why the US has stated that the ASBM has entered the initial operational phase. The space-based component is backed up by an Over-the-Horizon (OTH) radar system that provides real time information on the location of the CSG. The study projects that the error in the location of the carrier from all these assets for a missile to target an aircraft carrier can be conservatively estimated to be 25 km.

The missile has also been studied to the extent information is available in the public domain. Based on an evaluation of the warhead requirements for an anti-ship mission that includes an autonomous onboard radar with navigation and maneuver capabilities, an onboard propulsion system with sufficient fuel for reaching a mobile target as well as other requirements such as aerodynamic surfaces for terminal phase maneuvers, the warhead weight works out to be 1700 kg.

The assessment is that a missile of the DF-21 family can be modified to meet the mission requirements of an intermediate range anti-ship missile with a range of about 2000 km and a payload of about 1700 kg. The modifications needed to the known parameters of a typical

JL-1/DF-21 variant to strike a carrier have also been studied and the increases in the first stage and second stage masses of the existing JL-1 / DF-21 have been worked out. Measurements have also been made on a DF-21 D (ASBM) image available in the public domain. There is a good match between measurements and our predictions for the first and second stage lengths made from trajectory considerations. This does add credibility to Chinese claims on the ASBM.

Taking into account the space components, the OTH radar system as well as the readiness or near readiness of the DF21 Anti Ship Ballistic Missile it would appear that China has achieved an asymmetric equalizer to US carrier-based power projection capability.

While it is true that the ASBM has dramatically challenged the core of US sea power in the Pacific, it would be hasty and erroneous to predict China's supremacy over the region. The reality is that the US is two decades ahead of China in technology and has an alliance network that is a huge force multiplier in a conflict.

Countermeasures to the ASBM are neither self-evident nor easy to adopt. Both passive and active means have their limitations and disadvantages. Whatever be the combination of measures that the US chooses, it would appear that the ASBM has already achieved part of the intended effect by forcing a re-evaluation of the military equation and injecting an element of uncertainty in what was an unchallenged military scenario for the United States.

HF Over-the-Horizon (OTH) Radar

Introduction

Beyond-the-horizon detection of terrestrial targets at ranges of thousands of kilometers can be achieved by radars operating in the high-frequency (HF) band (3 to 30 MHz). This very long range coverage is obtained by using sky wave propagation that is, reflecting the radar signals from the ionosphere. Figures 1a, 1b, and 1c reveals that different range extents are illuminated by using different operating frequencies, with longer starting ranges requiring higher frequencies.

Figure 12: Ray-tracing through a model ionosphere, showing the variation of the radar footprint with carrier frequency. The contours map the plasma frequency or electron density.
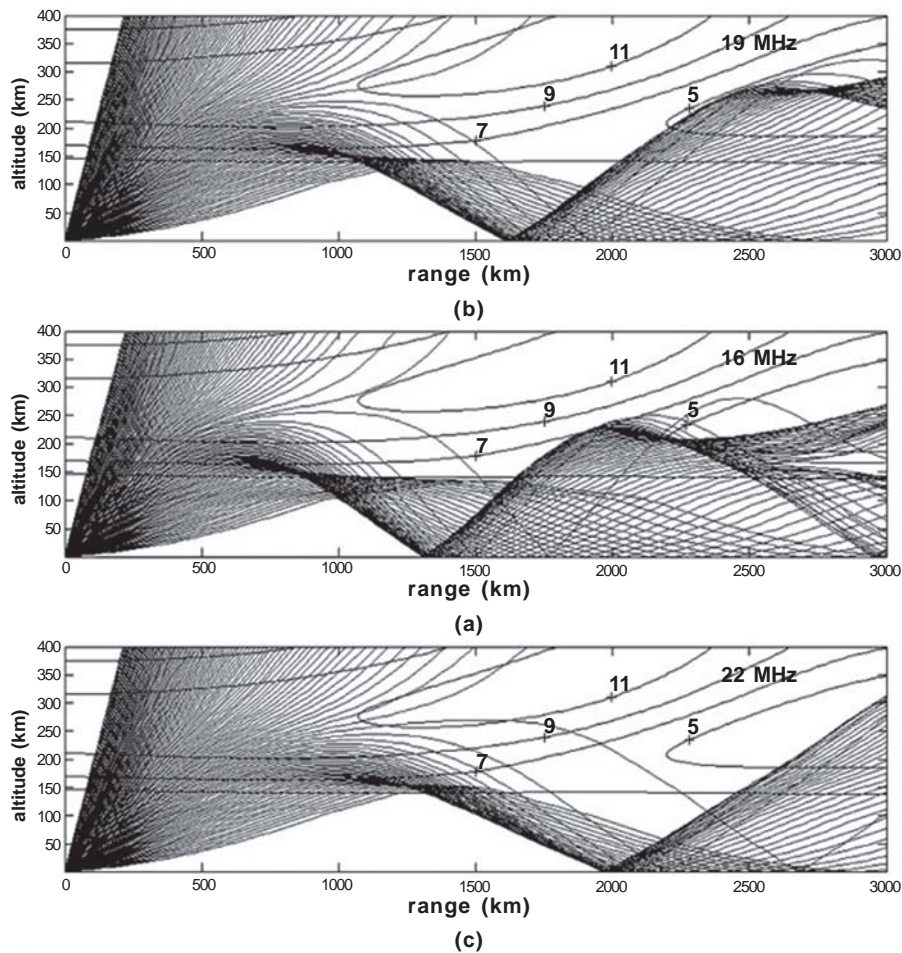
Limitations of conventional Radar Technology

Radio waves, a form of electromagnetic radiation, tend to travel in straight lines. This generally limits the detection range of radar systems to objects on their horizon due to the curvature of the Earth. For example, radar mounted on top of a 10 m (33 ft) must have a range to the horizon of about 13 kilometers, taking into account atmospheric refraction effects. If the target is above the surface, this range will be increased accordingly, so a target 10 m (33 ft) high can be detected by the same radar at 26 km. In general it is impractical to build radar systems with line-of-sight ranges beyond a few hundred kilometers. OTH radars use various techniques to see beyond the horizon, making them particularly useful in the early warning radar role.

Use of Ionospheric Reflections in OTH Radar

The most common method of constructing OTH radar is the use of ionosphere reflection. Given certain conditions in the atmosphere, radio signals broadcast up towards the ionosphere will be reflected back towards the ground. After reflection off the atmosphere, a small amount of the signal will reflect off the ground back towards the sky, and a small proportion of that back towards the broadcaster. Only one range of frequencies regularly exhibits this behavior. This is the high frequency (HF) or shortwave part of the spectrum from 3 – 30 MHz. Given certain conditions in the atmosphere, radio signals in this frequency range will be reflected back towards the ground. The "correct" frequency to use depends on the current conditions of the

atmosphere, so systems using ionospheric reflection typically employ real-time monitoring of the reception of backscattered signals to continuously adjust the frequency of the transmitted signal.

Since the signal reflected from the ground, or sea, will be very large compared to the signal reflected from a "target", some system needs to be used to distinguish the targets from the background noise. The easiest way to do this is to use the Doppler Effect, which uses frequency shift created by moving objects to measure their velocity. By filtering out the entire backscatter signal close to the original transmitted frequency, moving targets become visible. This basic concept is used in almost all modern radars, but in the case of OTH systems it becomes considerably more complex due to similar effects introduced by movement of the ionosphere itself.

Waveforms for the HF Radar

The factors that govern the choice of waveform in HF radar systems can be grouped into two classes. First, there are the considerations common to microwave radar that is, range and Doppler resolution as described by the ambiguity function and optimized for target detection and estimation, realizability in hardware, susceptibility to interference, efficiency, and the electrical properties of the scatterers of interest. The waveforms used in most operational HF skywave radars are variations on the periodic linear frequency-modulated continuous wave (LFM-CW) signal. Often, there is some provision for amplitude shaping, normally at the commencement and end of each sweep. The Jindalee radar was designed with the facility to apply a number of amplitude notches within the

sweep, thereby enabling the radar to sweep at zero amplitude across narrow-band users in the same frequency band without causing interference. Another class of variations involves departing from a linear frequency modulation. By varying the frequency-time characteristic of the waveform, range side- lobes can be reduced and spectral leakage can be controlled. Controlling the phase discontinuity from the end of one sweep to the beginning of the next provides another dimension in which the waveform properties can be optimized. Further generalization of the FM-CW waveform is possible by relaxing the condition that the waveform be periodic. This is a powerful tool for controlling range-ambiguous echoes, which can be shifted about in the range-Doppler plane to uncover previously obscured target echoes. Perhaps most importantly, in the congested HF spectrum where clear channels of adequate bandwidth to achieve the desired resolution may be scarce, FM-CW waveforms defined over two or more separate sub-bands are readily synthesized.

The Receiving System

The receiving system is defined here to embrace only the receiving antenna array and the receivers that convert the antenna outputs to discrete time series, usually at base- band.

There are many demands on the receivers for OTH radar, including high dynamic range, linearity, wide bandwidth, and uniformity between receivers when used in multi receiver systems. For most civil aircraft and ships, target radar cross section (RCS) at HF is roughly of the same order as the microwave RCS, that is, ~10–20 dBsm for aircraft and ~30–50 dBsm for ships,

but the range is 10–100 times greater, so the extra loss associated with R–4 is in the range 40–80 dB. Moreover, each target echo is immersed in clutter from the illuminated footprint, which may have an area of many thousands of square kilometers. Further, the HF signal environment includes (one-way) transmissions from powerful radio stations around the world, as discussed in the previous section. Imperfections in the receiver result in some of this noise and clutter energy being superimposed on the wanted radar echoes, either additively or multiplicatively. Hence, careful attention to receiver design is imperative if the radar designer wishes to avoid self-inflicted performance limitations.

Attempts to reduce contamination from external broadcast signals by inserting narrowband filters at the receiver front-end, sacrifice the high agility that is needed when the radar is changing frequency, typically by several MHz, second by second, as it jumps between tasks. There are also penalties from (i) filter switching time, (ii) settling time, (iii) distortion caused by group delay dispersion, and (iv) reduced reliability when there are hundreds of receivers. Further, each channel will need to account for the gain and phase variation for each filter, increasing the overheads on band switching. It is better to zero in on the bandwidth of interest by non-switched filters later in the receiver, using a variable frequency local oscillator to position the desired sub-band(s) over the selective filters. Of course the switched LO can also suffer from imperfections, but only one local oscillator is needed, as opposed to hundreds of receivers. Whichever design path is followed, the demands on receiver linearity and spurious free dynamic range are extreme.

Performance Evaluation for an ASBM Application

The specifications of the Chinese OTH radar are not available from public sources. Based on a review of the literature and information on existing radars an evaluation of the along track and across track resolution has been carried out. Conservatively this would suggest that the CSG can be located at distances of 2000 to 3000 km within a radius of 20 km.

Maneuverable Reentry Vehicle for DF-21 D

Reentry vehicles in general (and therefore DF-21 D will not be an exception) reach hypersonic speeds in their flight trajectory and controlling them and guiding them to their targets is quite a challenge. Ballistic missiles earmarked for nuclear weapon delivery do not need a very high order of targeting accuracy as the damage area of the weapon is large. In the case of missiles carrying conventional weapons, on the other hand a high order of target placement accuracy is essential. This necessitates the requirement of steerability to the reentry body, which can prove to be quite a challenge as the body will be rapidly decelerating and the reentry flight duration will be small.

1. The Reentry conditions

The environment experienced by a reentry vehicle is quite hostile in terms of the velocity, deceleration and the stagnation point heat transfer. These parameters are dependent upon the ballistic coefficient of the vehicle. The ballistic coefficient, β is defined as the mass of the vehicle divided by the product of the drag coefficient and the reference area. The reference area in the case of a reentry vehicle will be its base area and for normal designs, the value of β ranges from 500 to 1000 lb-m/ft2. Typical data taken from reference 1 is depicted in figure 13.

2. DF-21 D Reentry Vehicle

The DF-21 D image sourced from the internet and the dimensions derived from the image are shown in figure 14.

The RV structure is a cylinder-cone construction with a spherical nose cap. The reference diameter of the RV is found to be 1.4 m and the radius of

Figure 13: Reentry Parameters

a. Velocity (ft/sec)   b. Deceleration (g)   c. Stagnation Point Heat Transfer
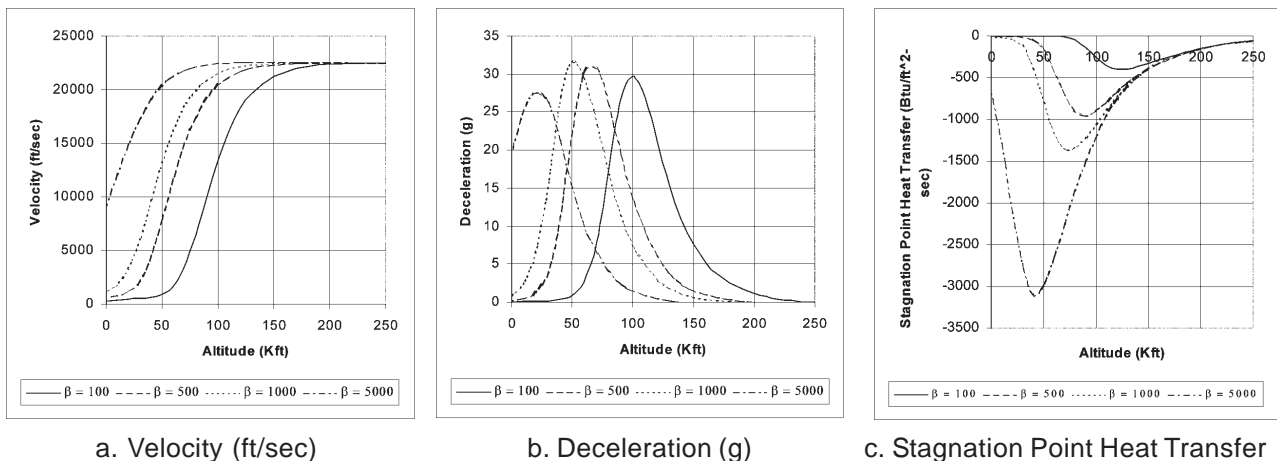
the nose cap as 0.35 m. The ratio of the nose radius to the base radius, called the bluntness ratio is a useful aerodynamic parameter and works out to 0.5 for the missile RV The drag coefficient and the lift to drag ratio of the RV are dependent upon the bluntness ratio.

At the reentry speeds shown in figure 1, it is difficult to maneuver the RV to its target. Consequently, it becomes necessary to reduce the reentry velocity, preferably to subsonic levels in order to steer the RV to its destination. Keeping this and other functional requirements in mind, the necessary constituents of the RV will be as follows:

- MMR radar — for target identification and homing
- High Explosive (HE) — for target damage/ destruction
- Battery — for providing power to the on-board systems
- OBC — On board command and sequencing of events
- NGC — Navigation and guidance unit
- Control thrusters — RCS unit to provide steering in pitch, yaw and roll
- Retro motor — For arresting the reentry velocity

Figure14: DF-21D RV Details
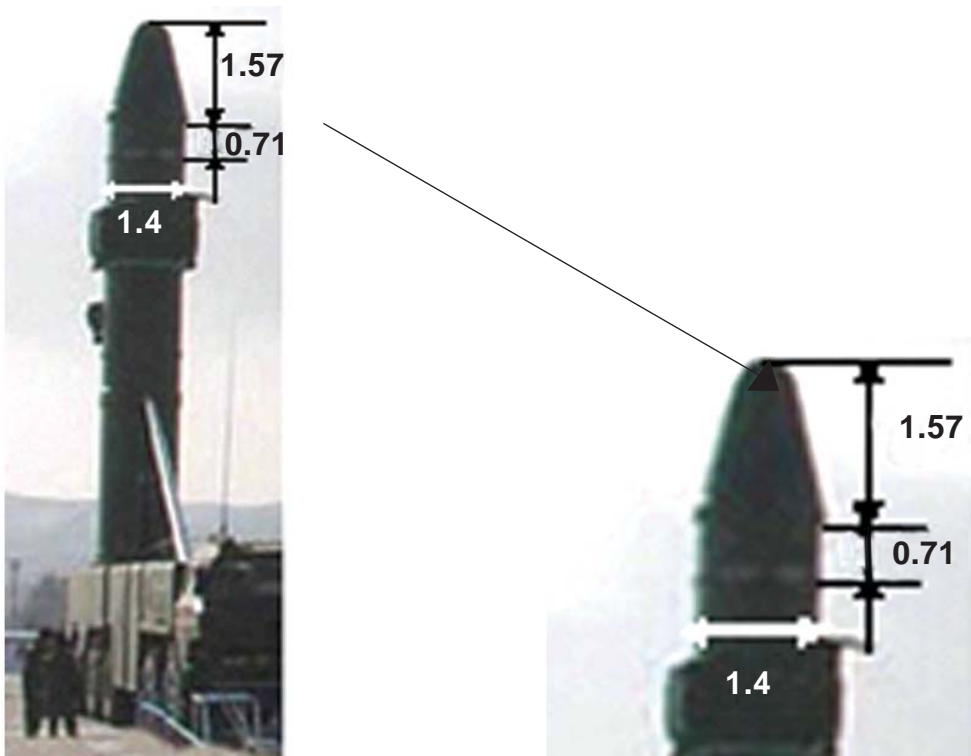
♦ Aerodynamic Flaps   For steering purposes

♦ Thermal Protection   For providing thermal protection to the RV constituents

One has to examine if all the above elements, except the thermal protection system (TPS), can be housed within the RV volume. The TPS obviously comes over the RV structure.

3. RV Layout

The primary requirement is reduce the velocity and this can be achieved using solid propellant retro motors mounted appropriately. Additionally a set of 8 RCS thrusters is envisaged to provide turning moments in the pitch up, pitch down, yaw left and yaw right directions. Roll control is automatically obtained by firing the opposite set of thrusters to produce a couple.

For this exercise, it is assumed that the maximum deceleration would be of the order of 8 g's. This seems to be a reasonable number as the reentry modules of manned space craft are aerodynamically designed to limit the deceleration to 8-10 g's. The forward force was computed and arbitrarily it was assumed that 70% of this force should be applied for retro braking maneuver.

Chandrashekar and Ramani, from the trajectory computation have figured a requirement of 200 kg of bipropellant for in-plane and out-of plane maneuvers of the RV to home in on the target. This propellant mass was equally divided among the 8 thrusters-4 each in the pitch plane and yaw plane. Bipropellant thrusters using

Table 7: RV Mass Breakup

Subsystem	Dimensions (in m)	Mass, kg
Airframe Structure	Cylindrical section 1.4 Φ x 0.7 Cone Frustum section 1.4 Φ x 0.7Φ x 1.2 Nose cap 0.7 Φ x 0.5	200
NTO Tank	600 Φ	6
NTO		150
MMH Tank	500 Φ	6
MMH		60
He Gas Tank	400 Φ	10
He Gas		2
Thrusters	0.3 Φ x 0.4 (each)	40
Plumbing, mounting brackets		20
Retro motors	150Φ x 575 (each)	100
High Explosives	1.0 Φ x 0.7Φ x 0.8	500
SAR	0.7 Φ x0.5	200
Avionics	Distributed	250
Power		50
Mechanical flaps and actuators		100
	Grand Total	1694 (say ,1700 kg)

nitrogen tetroxide (NTO) as oxidizer and Mono methyl hydrazine (MMH) as fuel could deliver a thrust of 7500 N per thruster. It must be noted that if the thruster is used in the pulse mode, the thrust will be lower and of the order of 7000 N. The pulse could be 200 to 500 milli-second duration.

Additionally, mechanical flaps could be attached to the base of the RV. The flaps could be stowed inwards during launch and deployed after the vehicle velocity is reduced. The actuation of the flaps will produce steering moments in the pitch, yaw and roll directions. It is conceivable that flap actuation can be usefully employed at altitudes in the vicinity of 20 km.

For managing the high values of stagnation point heat transfer (the temperature at the nose tip may exceed 1600 K), the metallic structure of the RV has to be protected using ablative liners made of carbon fibre reinforced plastics. The nose portion is generally made of carbon-carbon material which has superior mechanical and erosion resistant properties.

The dimensions of the retro motors, the RCS thrusters, tankage, high explosives have been worked out and the MMR radar dimensions and mass have been taken from manufacture's data. The total RV mass works out 1694 kg and is rounded off to 1700 kg. The details are show in Table 7.

A possible layout is also provided in figure 15. The RCS thrusters are located near the base of the RV to provide a long moment arm. The retro motors are provided near the top just above the location, where the high explosive pile is located.

**Figure 15:** RV Layout
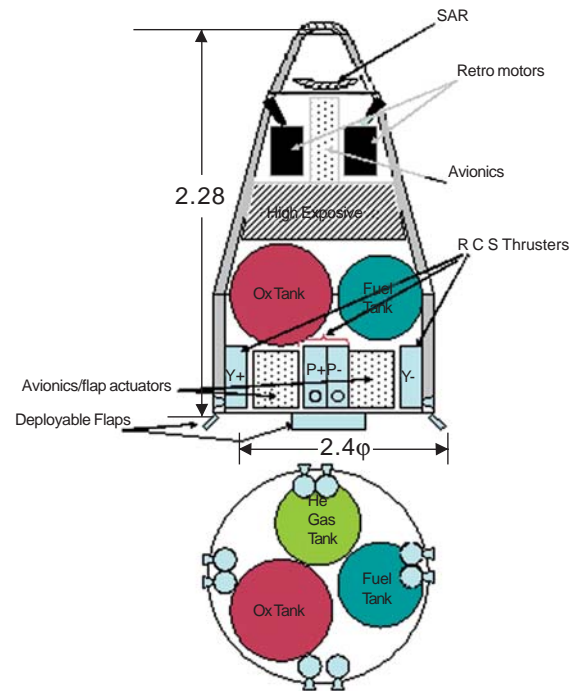
4.   Alternative Scheme

It is also possible to reduce the reentry velocity by affecting re-entry at a high angle of attack. The body offers a higher drag in this process, which helps in reduction of the deceleration and velocity. If required, a pull up maneuver can be performed followed subsequently by a ballistic path. In this process, time of flight can be increased, range can be increased and deceleration levels can be brought down to manageable levels. While such maneuvers are normally designed for MaRV's to avoid interception by defence systems, they can also be effectively used for guiding the MaRV to its target. Figure 16 shows the variation of CL/CD variation with angle of attack as a function of the vehicle bluntness ratio (ratio of the nose cone radius to the base radius).
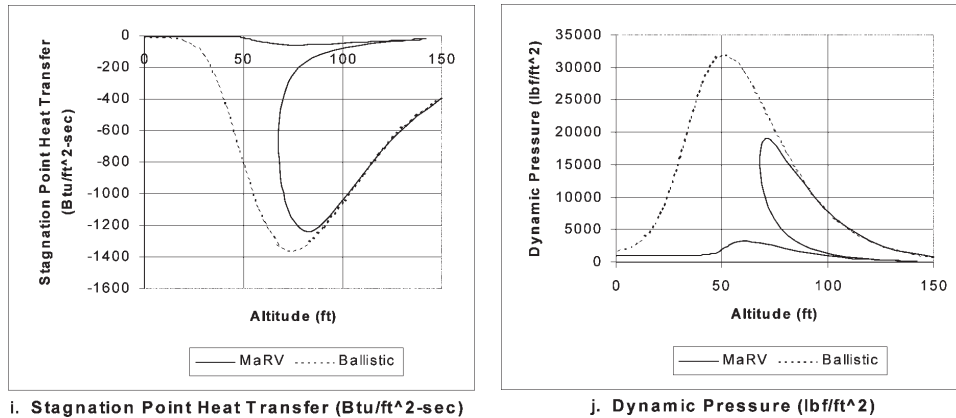
Figure 16: C_L/C_D vs bluntness ratio
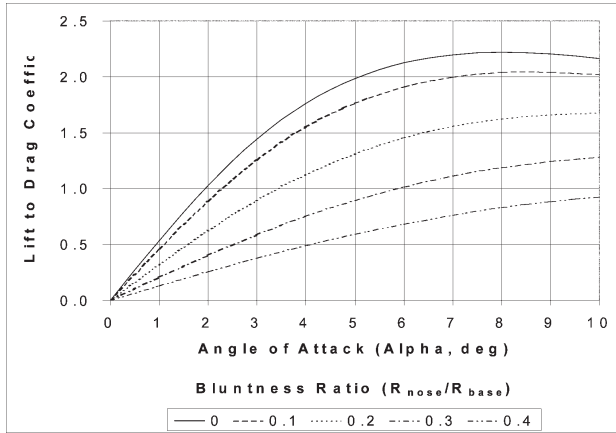
Figures 17 to 19 show an example of MaRV trajectory for a RV with ballistic coefficient of 1000. The flight sequence adapted here is as follows:

1.	Entry Altitude	250000 ft (76 km)
2.	Velocity	22500 fps (6.86 km/s)
3.	Flight Path Angle	12
4.	Application of L/D	At altitude of 150000 ft (45.7 km) constant L/D of 0.5 applied and maintained till altitude of 70000 ft (21.3 km)
5.	Pull up maneuver	At 70000 ft (21.3 km) to reach back altitude of 140000 ft (42.7 km)
6.	Final path	Ballistic like trajectory till impact

Figure 17: Comparison of ballistic and lifting body trajectories

a. Velocity (ft/sec)

b. Entry Time (sec)

c. Range (miles)
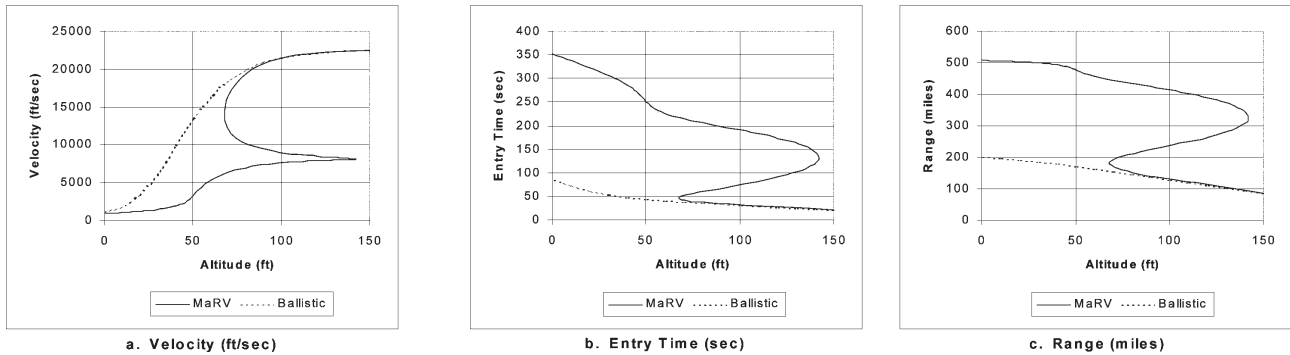
Figure 18: Comparison of ballistic and lifting body trajectories

d. Deceleration (g)

e. Mach Number
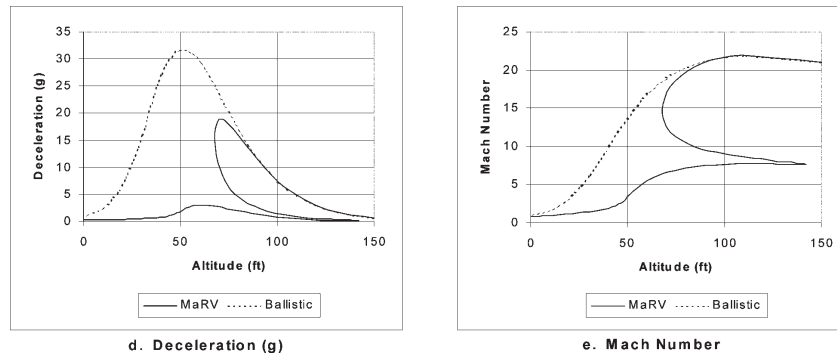
Figure 19: Comparison of ballistic and lifting body trajectories

i. **Stagnation Point Heat Transfer (Btu/ft^2-sec)**


j. **Dynamic Pressure (lbf/ft^2)**

The advantages derived from the lifting, pull-up and ballistic path over a pure ballistic trajectory are:

a) Increase in range by a factor of 2.5
b) Entry time increased to 325 sec over 85 sec for ballistic
c) Significant reduction in deceleration, stagnation point heat transfer and dynamic pressure.

The maneuverability to the reentry vehicle in pitch, yaw and roll directions can be provided by moving flaps. Such surfaces will be very effective once the velocity of the vehicle has been reduced. Bipropellant RCS systems can provide for attitude correction for maintaining the reentry L/D as well as for the pull-up maneuver.

The RV requirements are rendered much simpler with the above scheme of things. The retro motors can be dispensed with. The RCS functions also become simpler with one maneuver requirement of increasing the reentry angle of attack-all other maneuvers will be executed through the movable flaps. The revised layout of the RV shown in figure 20 highlights this aspect.

Figure 20: Revised RV Layout
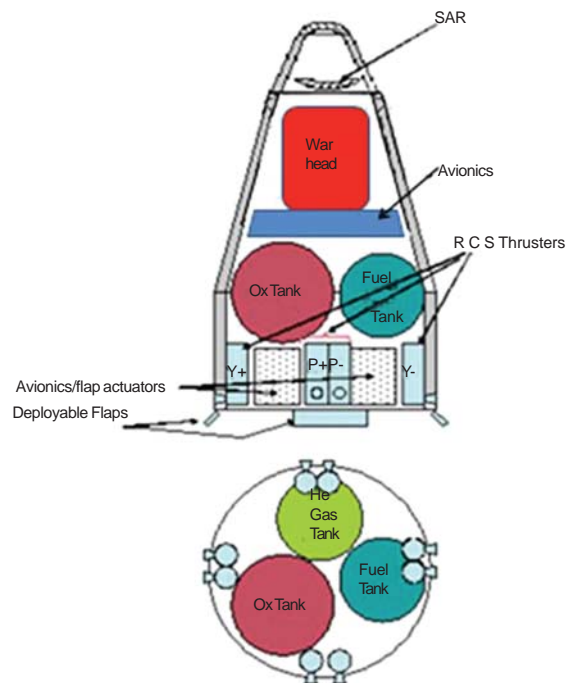
The elimination of the RV leaves more space for laying out the high explosives, the RCS and the avionics systems. The mass and space earlier utilized for housing the retro-motors can be used for storing decoys. The pull-up maneuver is a desirable feature if one wants to increase the flight time and can be executed through the use of flaps. The RCS thrusters will be used only for 3-axes stabilization and not fur executing maneuvers. It is possible by judicious choice of materials and layout, the mass of the RV could be reduced by 200-300 kg and the resulting saving could help in either increasing the payload or increasing range of the missile.

5. Conclusion

The DF-21 Maneuverable warhead details are studied based on the dimensions derived from open source imagery. It seems that the warhead can be designed to be slowed either aerodynamically or through the use of retro motors. Further mission objectives can be met either by planning maneuverable descent or by using reaction control motors. Possible layout and mass breakup is worked out.

References:

1. John C Adams Jr, Atmospheric Reentry, June 2003, http://exoaviation.webs.com/pdf_files/Atmospheric%20Re-Entry.pdf accessed on 10 June 2011.

2. US conventional Prompt Global Strike, Issues for 2008 and beyond, National Academies Press, Washington DC.

ASBM Scenario [29]

Qiu Zhenwei and a coauthor state that by 2010 the Second Artillery Corps will control one ASBM brigade, armed withDF-21E ASBMs.

In Qiu's scenario, the PLA tracks three approaching U.S. CSGs with synthetic-aperture-radar / optical reconnaissance satellites, 2,500–3,500-kilometer sky-wave OTH radar, and "land listening stations." U.S. attempts at interference only improve targeting. PLA forces obtain the carrier's position from "radio signals transmitted when communicating via [Link16]" and confirm it from "signals emitted by the air search radar, air control radar, and aircraft approach guidance radar."

DF-21E ASBMs are launched in two wave attacks with "a special incendiary agent and additive, as well as the dispersal of gas in the sky above" to reduce the initial infrared signature.

A "third-stage rocket engine" gives the ASBMs a depressed trajectory, "with multiple peaks" and "increasingly violent maneuvers," that is "extended by 300 km and dropped by 10 km." To compensate for the fact that the homing "antenna window" remains open, the warheads are further concealed by a cooled shroud, balloon decoys, and symmetrical spinning, thereby defeating SM-3 interceptors.

To eliminate inaccuracy of 15–42 km on a 1,100 km flight using aerodynamic flight forces to extend range, "high-altitude homing" is conducted through "radio command amendments" from satellites (including ones recently launched to support military operations), "unmanned reconnaissance aircraft," multimode "microwave radiometers," and sky-wave/passive radar.

This is followed by "terminal infrared image homing," during which the warheads adopt an "unpredictable swinging trajectory," thereby "easily evading air defense missiles." Twelve and a half minutes after launch, the first four DF-21E ASBMs strike the targeted CSG destroyers, either "sinking the ships or inflicting severe damage to their ammunition warehouses and engine rooms." Three minutes later, a second salvo strikes the three aircraft carriers.

The author maintains that "a conservative set of ASBM data has been used for this scenario; for example, the hypothetical [radar cross section] of the warhead was 0.001 square meters, the warheads did not electronically jam the data link of the radar or intercept missile or the GPS navigation of the intercept missile, many missiles were not launched simultaneously to create confusion, and anti

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[29] Andrew S. Erickson and David D. Yang, "Using The Land To Control The Sea? Chinese Analysts Consider the Antiship Ballistic Missile", Naval War College Review, Autumn 2009, Vol. 62, No. 4, reference 66, pp. 84-85 provide a scenario of how the ASBM will work. Erickson & Yang are skeptical about the knowledge of one of the authors to address this complex problem.

ship missiles did not attack the destroyers that had given up their air defense capabilities." While stating that "in the foreseeable future, there will be many ways to shoot down anti ship ballistic missiles that use countermeasures," due to advances in missile tracking capabilities and interceptors, the author cites many "weaknesses of the U.S. military's entire system" and concludes that "at the very minimum, the aggressor will hold the advantage prior to 2020."

Qiu Zhenwei and Long Haiyan, "930 Seconds," pp. 27–34.