Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–2001/03 January 2001

Survivability, Structures, and Materials Directorate

Technical Report

Structural Analysis of Helicopter Flight and Hangar Decks

by

Jessica Stainback

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NSWCCD-65-TR–2001/03 Structural Analysis of Helicopter Flight and Hangar Decks

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY
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9130
Ser 65-35
23 Jan 01

From: Commander, Naval Surface Warfare Center, Carderock Division
To: Commander, Naval Air Systems Command (AIR 7.6.2)

Subj: HELICOPTER HANDLING DECK CERTIFICATION

Ref: (a) Work Request N0001900WXCF07Y

Encl: (1) NSWCCD-65-TR–2001/03, *Structural Analysis of Helicopter Flight and Hangar Decks*

1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to certify air capable ships for operations with Navy helicopters CH-60S and SH-60R. Enclosure (1) is a manual to accompany DDS 130-2. Both documents describe the procedure used to analyze the strength of helicopter handling decks.

2. Comments or questions may be referred to the author, Ms. Jessica Stainback, Code 651; telephone (301) 227-5374; e-mail, StainbackJ@nswccd.navy.mil.

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BETHESDA MD [Codes 3442 (TIC), 60 (w/o encl), 65, 65R (2), 651 (15), 652, 653, 654, 655]

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Enclosure (1)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
22-Jan-2001

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
-

4. TITLE AND SUBTITLE
Structural Analysis of Helicopter Flight and Hangar Decks

5a. CONTRACT NUMBER
N0001900WXCF07Y

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Jessica Stainback

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

Naval Surface Warfare Center
Carderock Division
9500 Macarthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER

NSWCCD-65-TR-2001/03

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Attn AIR 7.6.2
Commander
Naval Air Systems Command
1421 Jefferson Davis Hwy
Arlington VA 22243

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This publication clarifies and modernizes the text in the current Design Data Sheet, DDS 130-2, used to analyze the structural strength of US Navy ship helicopter flight and hangar decks. This document explains the DDS 130-2 procedure to provide a better understanding of the methodology. The DDS 130-2 and this document provide a uniform standard and simplified method for the strength analysis of the helicopter flight and hangar deck structure on US Navy Ships. The analysis method is specifically for helicopter operations. Any other loading conditions or aircraft operations in the handling areas should be considered separately. The DDS 130-2 includes helicopter with both wheeled and skid type landing gear, this paper focuses on helicopters with wheeled gears only.

15. SUBJECT TERMS
ship structures, helicopters, flight and hangar decks

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Jessica Stainback
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	67	**19b. TELEPHONE NUMBER** *(include area code)* (301) 227-5374

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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The work described in this report was performed by the Structures and Composites Department (Code 65) of the Survivability, Structures and Materials Directorate at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The work was funded by the Naval Air Systems Command (AIR – 7.6.2) as requested by work request number N0001900WXCF07Y.

This paper was presented to the University of Maryland as partial fullfilment of the requirements for the degree of Master of Science in Civil Engineering. The work was partially funded by the Naval Air Systems Command.

Acknowledgements

The authors would like to thank the several individuals for their contribution to this work. Valuable comments and suggestions were made by James Rodd and Ely Fishlowitz (NSWCCD 651). Advice, background information, and explanations on DDS 130-2 were provided by Michael Sieve (NAVSEA 05P1) and Gregory Woods (NSWCCD 652). Major Ian Lightbody CAF (NAVAIR PMA-299) provided background information for helicopter handling and operations. University of Maryland professor Dr. Pedro Albrecht made additional comments and suggestions.

Summary

Each flight-capable ship is certified for operations with specific helicopters. Before a ship is certified for a particular helicopter, the entire handling area must be analyzed to ensure that the deck structure will safely support the landing and parking of the helicopter. The current Design Data Sheet, DDS 130-2 (Naval Sea Systems Command, 1984), provides a uniform standard and simplified analysis method for the handling area structure on US Navy Ships. This analysis determines the resulting stresses on the deck structure imposed by helicopter operations. Then, the procedure compares the imposed stresses to the permissible stresses as discussed herein. If the imposed stresses are less than those permitted, then the ship can be certified and operations with a particular helicopter may proceed.

The following is a detailed procedure on how to analyze helicopter-handling decks for US Navy ships. This paper is a guide to Design Data Sheet DDS 130-2 (Naval Sea Systems Command, 1984). DDS 130-2 is the standard analysis method set by the Naval Sea Systems Command (NAVSEA) to certify ships for operations with helicopters. This guide discusses each aspect of the analysis. The landing and parking of a helicopter on the ship's flight and hangar deck induces stresses in the structure. These stresses depend upon the helicopter weight and characteristics, sea condition, ship motion, and framing properties. The calculated stresses are compared to the allowable stresses of the structural material. If the calculated stresses are less than the allowable stresses then that specific type of helicopter can operate with that ship. Each part of this guide explains different aspects of the procedure with the associated calculations.

Introduction

This paper is a guide to clarify the procedure outlined in Design Data Sheet, DDS 130-2, which is used to analyze the structural strength of helicopter flight and hangar decks on US Navy ships. This document explains the DDS 130-2 procedure to provide a better understanding of the methodology. The DDS 130-2 and this document provide a uniform standard and simplified method for the strength analysis of the helicopter flight and hangar deck structure on US Navy Ships.

The analysis method is specifically for helicopter operations. Any other loading conditions or aircraft operations in the handling areas should be considered separately in accordance with the *General Specifications for Ships of the U.S. Navy* (NAVSEA) and the *Structural Design Manual for Surface Ships of the U.S. Navy* (NAVSEA). In addition, the DDS 130-2 includes helicopters with both wheeled and skid type landing gear. This paper focuses on helicopters with wheeled landing gear only. If a helicopter with skids requires certification, this paper is applicable, however refer to DDS 130-2 for the loading calculations.

This procedure is an adaptation from the *Design Manual for Orthotropic Steel Plate Deck Bridges* (American Institute of Steel Construction, 1963) and the *Design of Deck Structures under Wheel Loads* (Royal Institute of Naval Architects, 1980). The analysis incorporates Navy experience and research. Member interaction and static indeterminacy of the deck structure are taken into account. The plating analysis incorporates localized plasticity, membrane effects, and makes use of simplified approximations for the elastic-plastic behavior. The longitudinal stiffener analysis incorporates the transverse beam flexibility effects and grillage effects. The approach is based on strip theory and use of design curves and influence lines is extensive. Only the governing load placement of the helicopter gears is used to determine the maximum stress in the deck plating and longitudinal stiffeners. Naval Sea Systems Command (NAVSEA) has developed a spreadsheet to facilitate the analysis. In September 2000, the Naval Surface Warfare Center, Carderock Division (NSWCCD), Code 651 updated the spreadsheet.

Operations and Conditions

General Helicopter Operations

Helicopter operations aboard US Navy ships are standardized by the Naval Air Systems Command (NAVAIR), which outlines procedures for securing and handling helicopters in the technical manual *Aircraft Securing and Handling* (NAVAIR). The conditions of the sea and the ongoing helicopter operation will determine how exactly these procedures will be carried out.

Helicopters usually land in the designated circle on the flight deck, but may need to land outside the circle during a special operation. Therefore, the deck must be analyzed for landings anywhere. "Loading" suggests several spots.

The orientation of the helicopter with respect to the ship affects the loading acting on the deck structure. Ships such as frigates, destroyers, and auxiliaries normally have small flight decks. On these decks, the helicopter parks at an angle with respect to the ship, and location variations are limited. On larger ships, such as amphibious assault ships, the helicopter parks either longitudinally or transversely with respect to the ship, and the location can vary over the length and breath of the ship. The location affects the magnitude of the load. The orientation determines how the individual structural members must be loaded. Assume that the longitudinal or athwartship orientation produces greater loading conditions than angled orientations. Therefore, in the analysis consider only the longitudinal and athwartship orientations.

The length of time the helicopter stays aboard ship determines where and how it is tied down. During short stays, the helicopter is immediately chocked and chained where it landed. During longer stays, the helicopter is moved into the hangar, if one is available. Armament is removed when the helicopter stays aboard longer or before it is moved into the hangar. This reduces the weight of the helicopter, and decreases the hazard risk to the ship. If the helicopter is aboard for only a short period, then the armament may remain on the helicopter. The helicopter is moved into the hangar either via an aircraft elevator, Recovery Assist, Securing, and Traversing (RAST) system, or by manual and equipment hauling. Once in the hangar, the helicopter is chocked and chained. The chocks and chains are defined as tiedowns in the following analysis. If the ship has an aircraft elevator, then that elevator must also be analyzed and certified.

The current sea condition determines the operation status. Helicopters are to land and transit only in light to moderate sea conditions. A heavy sea landing can occur only if the ship has a RAST system. Use aircraft elevators only through moderate seas. During storm seas, park all helicopters in the hangar, if possible. On ships with large flight decks or without hangars, the flight deck structure should support parking during storm seas. Otherwise, the helicopter must disembark.

Recovery Assist, Securing, and Traversing (RAST) System Operations

Some smaller ships are equipped with a RAST system, which enables the LAMPS MK III (SH-60B) and similar helicopters to land and move into the hangar in heavy sea conditions.

The RAST system consists of three parts: recovery assist, rapid securing, and the RAST track. The recovery assist system aboard the ship and the helicopter's securing system work together to guide the landing of the helicopter. The recovery assist system consists of two winch driven cables, which help to reduce landing dispersions. The rapid securing device is a vise-like trap on the deck. This system uses a probe to aid the helicopter landing and transiting. The probe attaches underneath the helicopter between the main gears. The probe comes up from the track through the rapid securing device to connect to the helicopter. The rapid securing device and the probe run along the track to transit the helicopter into the hangar.

While the helicopter is hovering above the deck, just before touchdown the cables are attached to the helicopter. The recovery assist cable can apply up to 5000 pounds of constant tension to guide the helicopter main gear probe connection into the rapid securing device probe. After the probe is attached to the helicopter properly and the helicopter has landed, the jaws of the device close to secure the probe. Once secured, the tension in the cables is released. The cables are then attached to the helicopter tail to align the tail with the RAST track for transiting. Once aligned with the track, the helicopter is moved into the hangar by the system. This setup helps prevent the helicopter from sliding or overturning on the deck. Furthermore, the probe is an integral part of the system and is rarely removed during the entire time the helicopter is aboard.

Landing and Parking

This analysis considers only the loading conditions imposed by the helicopter on the handling area structure. The landing and parking of the helicopter are the two loading conditions. The landing condition is the touchdown of the helicopter on the deck. The helicopter main and auxiliary gear reactions on the deck are the landing loads. The landing condition includes the longitudinal and athwartship helicopter orientations as separate cases. After the landing, the remaining time the helicopter is aboard is the parking condition. The parking condition must consider storm and moderate seas as two different cases. Then both helicopter orientations must be analyzed for each sea condition. The maximum gear reactions determined for the maximum weight (fully loaded) and parking weight are the parking loads.

Storm and Moderate Seas

As mentioned before, there are restrictions and procedures for helicopter operations in different sea conditions. The sea condition only effects helicopter parking loads. This analysis only considers storm and moderate seas. Storm seas relate to a Sea State 7, and moderate seas to a Sea State 5. The North Atlantic Treaty Organization (NATO) sets the following design criteria for the two sea states (NATO):

Sea State 7:

- Moderately high waves
- 24-ft significant wave height
- Wind velocity of 48 to 55 knots
- Visibility is reduced
- There is a 5 percent chance that a ship will be in an environment exceeding a Sea State 7 during average ship service at sea

Sea State 5:

- Moderate waves
- 10-ft significant wave height
- Wind velocity 22 to 27 knots
- There is a 30 percent chance that a ship will be in an environment exceeding a Sea State 5 during average ship service at sea

Significant wave height is the average wave height of the highest one third of the waves.

Ship Motions

After landing the helicopter is subject to inertial forces produced by the ship's motions, which include the roll, pitch, yaw, surge, sway, and heave. These forces effect the entire ship and its holdings. The effect varies depending upon the location in the ship. Generally, the greater the distance from the ship's center of motion, the greater the inertial force. These forces are also dependent on the ship's characteristics, such as the ship's response to a sea condition. Motion coefficients are developed for each ship and are provided in the ship specifications (NAVSEA). These coefficients along with the holding self-weight determine the acting inertial forces.

Loading

The following are suggested locations in the helicopter handling area for analysis:

(1) Center of landing circle
(2) Outboard and aft of landing circle
(3) Transition from landing circle to hangar
(4) Hangar

These locations are subjected to the following load cases:

(1) Landing, longitudinal orientation
(2) Landing, athwartship orientation
(3) Parking, storm sea condition, longitudinal orientation
(4) Parking, storm sea condition, athwartship orientation
(5) Parking, moderate sea condition, longitudinal orientation
(6) Parking, moderate sea condition, athwartship orientation

This part explains the steps to calculate the applied load, or critical gear load R, used in the analysis. Below is a loading summary for all cases. Note, the landing load case does not apply for locations in the hangar.

The critical gear load, R, is determined from the combination of the gear reaction and loading distribution which creates the worst loading condition for the given sea condition and helicopter orientation. The gear load distribution effects can vary between gears due to the number of wheels, tire size, or operational pressure. Gear load distribution is discussed in "Wheel Load Distribution." Both the load magnitude and the wheel distribution affect the strength analysis. If the gear load reactions are close in value, then perform a strength analysis on both of the gear reactions. Normally, the load magnitude has the larger effect, therefore:

Critical Gear Reaction Load R = maximum helicopter gear reaction (R_2, R_A)

Load Case Summary

Landing (both orientations):	maximum nominal helicopter gear reaction
Parking (both orientations):	maximum calculated gear reaction
Storm Seas	
Flight deck:	helicopter parking weight (ship motion factors) + tiedown force + wind force
Hangar deck:	helicopter parking weight (ship motion factors) + tiedown force
Moderate Seas	
Flight deck:	helicopter maximum weight (ship motion factors) + wind force
Hangar deck:	helicopter parking weight (ship motion factors)

Landing Loads

The landing load only applies on the flight deck. For the landing calculations use the nominal landing reaction as the critical gear load R, which is provided by the helicopter manufacturer. The manufacturer bases these results on their own laboratory tests and analysis. Gear loads are probabilistic and depend on the rate and attitude of descent, gear configuration, tire characteristics, and helicopter landing weight. Gear loads should be representative of the maximum expected load resulting from normal operations, not the maximum gear collapse load. Past landing load predictions have been based on a sink rate of 12 ft/s, which is a very harsh landing. During current discussions it has been recommended to base the loading prediction on an 8 ft/s sink rate, still a hard landing.

Parking Loads

The parking load applies to all the handling areas. The critical gear reaction is a function of helicopter inertial loads due to ship motions, helicopter tiedown forces, wheel friction, and wind forces. How to determine each of these factors is discussed in this section.

Analyze for both storm and moderate seas at both helicopter orientations. Parking loads are highest during storm seas and most frequent during moderate seas. Generally, the former are about twice as high as the latter.

When ship motions are not affecting the helicopter, the weight is proportionally distributed between the three wheels. This even distribution to the gears is the static gear load reactions. When ship motions are affecting the helicopter, the weight is unevenly distributed, as is the case here. The helicopter manufacturer provides two helicopter weights:

Wm	helicopter, fully fueled, armed, with crew (kip)
Wp	helicopter, fully fueled without armament and crew (kip)

The flight deck is designed to support the maximum weight; the hanger, the parking weight. During storm seas the helicopter must have its armament removed, therefore the weight is reduced to the parking weight. Table 1 summarizes the design load as a function of the sea condition and location on the ship.

Table 1: Helicopter Weight for Deck Analysis

Sea Condition	Location on Ship		
	Flight Deck	Hangar Deck	Elevator Platform
Storm Seas	Wp	Wp	N/A
Moderate Seas	Wm	Wp	Wp

Ship Motion Loads

Ship motions apply an inertial force increasing the weight of the helicopter. The ship motion loads depend on the ship motion factors. These factors are a function of the distance from the helicopter's center of gravity to the ship's assumed center of motion and on the characteristics of the ship. In the *General Specifications for Ships of the U.S. Navy*, Section 070 or Section 9020-01 (NAVSEA) lists coefficients, which represent the ship characteristics. Coefficients are provided for storm seas, with factors relating to moderate seas. The ship motion factor equations are as follows:

$K_{1\text{-}12}$	ship motion coefficients
X	longitudinal distance from helicopter CG to longitudinal center of motion of ship (ft)
Y	transverse distance from helicopter CG to ship centerline (ft)
Z	vertical distance from flight deck to vertical center of motion of ship (ft)
Z_G	height of helicopter CG above flight deck (in)

Ship Motion Factors – Storm Seas

Forward and aft: $$\eta_{xs} = K_1 + K_2X + K_3\left(Z + \frac{Z_G}{12}\right)$$

Port and starboard: $$\eta_{ys} = K_4 + K_5X + K_6Y + K_7\left(Z + \frac{Z_G}{12}\right)$$

Downward: $$\eta_{zs} = K_8 + K_9X + K_{10}Y$$

Ship Motion Factors – Moderate Sea Conditions

Forward and aft: $$\eta_{mx} = K_{11}\eta_{xs} \cdots or \Rightarrow \tfrac{1}{2}\,\eta_{xs}$$

Port and starboard: $$\eta_{my} = K_{12}\eta_{ys} \cdots or \Rightarrow \tfrac{1}{2}\,\eta_{ys}$$

Downward: $$\eta_{mz} = \frac{1 + \eta_{zs}}{2}$$

If the K_{11} and K_{12} coefficients are not specified, then set as one half.

The ship motion forces are the product of the ship motion factors and the helicopter weight specified in Table 1. These ship motion forces act at the center of gravity of the helicopter and produce the deck loads.

F_i	ship motion force in *i* direction (kip)
η_i	ship motion factor in *i* direction
W_j	weight of helicopter for *j* condition (kip)
i	x, y, and z directions with respect to ship
j	maximum or parking weight of helicopter, according to Table 1

Ship Motion Force

$F_i = \eta_i W_j$

Helicopter Orientation

The orientation of the helicopter with respect to the ship affects how the individual structural members must be loaded. Each ship motion induced load must be reoriented with respect to the helicopter for each loading orientation.

F_L	ship motion force longitudinal to helicopter (kip)
F_T	ship motion force transverse to helicopter (kip)
F_D	downward ship motion force (kip)

Force Orientation

Helicopter oriented longitudinally to ship:

$F_L = F_X$
$F_T = F_Y$
$F_D = F_Z$

Helicopter oriented athwartship:

$F_L = F_Y$
$F_T = F_X$
$F_D = F_Z$

Wind Loads

The wind force is a concentrated load applied at the center of pressure, in the transverse direction of the helicopter. Calculate the concentrated load by multiplying a uniform pressure by the sail area of the helicopter. The sea state determines which pressure and sail area to use. For storm seas, the pressure is 15 pounds per square foot; moderate seas, 7.5 pounds per square foot. There are two sail areas provided by the manufacturer, folded and unfolded. The sail area is the exposed surface area of the helicopter. A folded sail area is when the rotors are turned and the horizontal stabilizer panels raised. The helicopter is folded for storm seas and storage in hangar. Therefore, use the folded area for storm seas and the unfolded for moderate. When the helicopter is in the hangar, no wind load applies. Also, note that the folded sail area can be larger than the unfolded; more area is exposed to the wind pressure.

F_W	wind force (kip)
a_s	sail area of the helicopter (ft^2)

Wind Loads

Storm seas:

$$F_W = 0.015a_s$$

Moderate seas:

$$F_W = 0.0075a_s$$

Tiedowns

Once on the ship the helicopter is chocked and chained to prevent sliding and overturning. The chocks and chains act as restraining forces helping to reduce the gear reaction values. These retraining forces are simplified into one equivalent force applied to on the windward side of the helicopter, called the tiedown force. The tiedown force equation is discussed further in the Gear Reaction section. The manufacturer provides the equivalent location data, Z_T and Y_T, and angle, Ω, for storm and moderate seas. Tiedowns are only effective when an overturning moment acts on the helicopter. Larger gear reactions result from a slacked tiedown, i.e. a tiedown with no applied force.

Equivalent tiedown locations differ for storm and moderate seas. NAVAIR Technical Manual, *Aircraft Securing and Handling* describes four types of configurations, initial, intermediate, permanent, and heavy weather. These configurations depend on the operation status and sea conditions. Four chains are used for initial tiedowns, and are required up to the time of any helicopter movement, immediately after parking, or after recovery. Intermediate tiedowns include six chains, which are required for flight quarters when the helicopter may be moved. When not at flight quarters, permanent tiedowns of 12 chains are required. Heavy weather tiedowns of 18 chains are applied at the direction of the Aircraft Handling Officer.

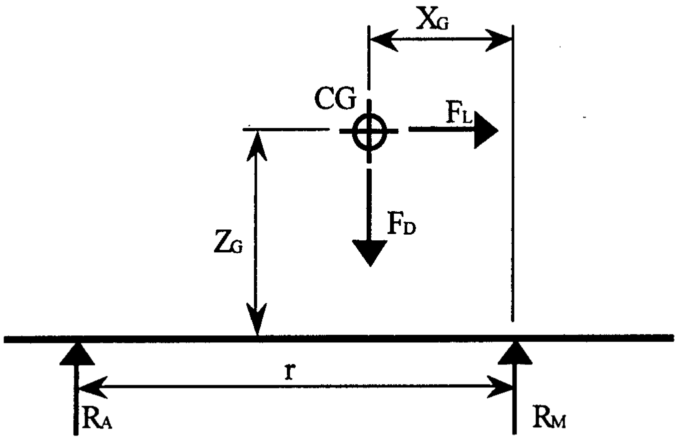
Gear Reactions

A typical helicopter has three wheeled gears: two main gears and an auxiliary gear (Figures 1 and 2). Longitudinal ship motion loads cause uneven distribution between the main and auxiliary gear reactions. The wind, tiedown, and transverse ship motion loads cause uneven distribution between the two main gear reactions.

Determine the gear reactions as follows:

1. Use the longitudinal free body diagram of the helicopter to balance the loading between the main and auxiliary gears, R_M and R_A (Figure 1).

2. Use the transverse free body diagram to balance the loading between the two main gears, R_1 and R_2 and the tiedowns (Figure 2).



CG	center of gravity of helicopter
r	distance between auxiliary and main gears (in)
R_A	auxiliary gear reaction (kip)
R_M	total main gear reaction (kip)
X_G	distance from main gear to CG (in)
Z_G	vertical distance to CG (in)

Figure 1: Longitudinal Free-Body Diagram of Helicopter

Maximum main gear reaction, R_M, from moment equilibrium about auxiliary gear:

$$R_M = F_D\left(1-\frac{X_G}{r}\right)+F_L\left(\frac{Z_G}{r}\right)$$

Maximum auxiliary gear reaction, R_A, from moment equilibrium about main gear:

$$R_A = F_D\left(\frac{X_G}{r}\right)+F_L\left(\frac{Z_G}{r}\right)$$

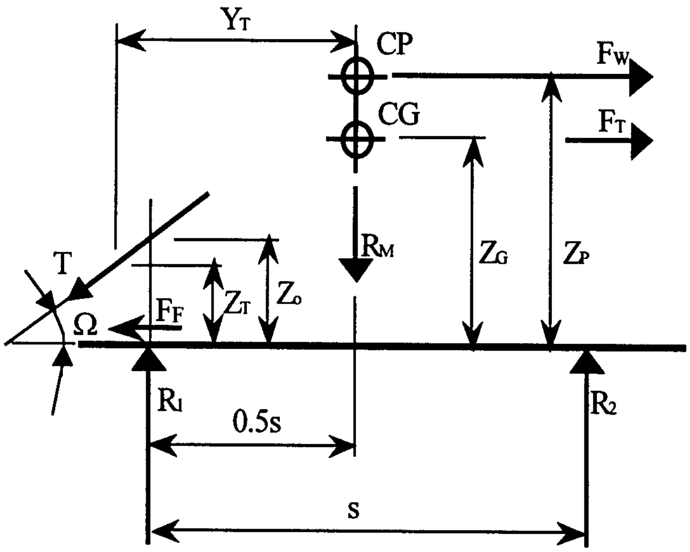
The two values calculated do not occur simultaneously. The larger reaction is used in the subsequent analysis. To insure equilibrium the following equations are used to calculate the other non-critical gear reaction.

When the main gear is larger, determine the auxiliary gear reaction from force equilibrium:

$$R_A = F_D - R_M$$

When the auxiliary gear is larger, determine the main gear reaction from force equilibrium:

$$R_M = F_D - R_A$$



CP	center of pressure on helicopter
F_F	friction force (kip)
$R_{1,2}$	main gear reactions (kip)
s	main gear spacing (in)
T	tiedown force (kip)
Y_T	distance from CP to tiedown location (in)
Z_P	vertical distance from deck to CP (in)
Z_0	vertical distance of tiedown lever arm (in)
Z_T	vertical distance from deck to tiedown location (in)
Ω	tiedown angle (deg)

Figure 2: Transverse Free-Body Diagram of Helicopter

Next using Figure 2, to simplify calculations, resolve the tiedown location data into an equivalent tiedown lever arm, Z_o. This lever arm is directly above the main gear reaction R_1, which allows the vertical tiedown component to be neglected for moment summations about R_1.

$$Z_o = Z_T + \left(Y_T - \frac{s}{2}\right)\tan\Omega$$

After calculating the reactions for the main and auxiliary gears, calculate the overturning moment, M. If the helicopter has a positive overturning moment, then the tiedown force applies. If the overturning force is negative then the tiedown force is not effective. After calculating M, compute the two main gear reactions, which are different for the two conditions of $M \le 0$ and $M > 0$.

***Helicopter Overturning Moment, M*:**

$$M = F_W Z_P + F_T Z_G - R_M \frac{s}{2}$$

No Overturning Moment, $M \leq 0$

If $M \leq 0$, then the tiedown is not loaded, $T = 0$; and the helicopter is not being overturned.

Main gear reaction, R_2:

$$R_2 = \frac{R_M}{2} + \frac{F_W Z_P}{s} + \frac{F_T Z_G}{s}$$

Main gear reaction, R_1:

$$R_1 = R_M - R_2$$

Positive Overturning Moment, $M > 0$

If $M > 0$, then the tiedown is loaded and preventing the helicopter from being overturned.

Note, the tiedown force T has a horizontal component. In order to prevent the tiedown force from being over predicted and the gear reaction under predicted, an estimate of the tire friction force F_F is included. The resulting system has more unknowns than equations. Therefore, the gear reaction R_1 is assumed to equal the static gear load. The static gear load is a portion of the helicopter load at parking weight with no ship motion loads applied. This assumption is reasonable because the tiedown chains are applied manually without preloading, i.e. compressing the gear beyond the static gear load. Otherwise, if the applied chain did compress the gear, then it would be impossible to remove the chains manually.

Main gear reaction, R_1, static gear load:

$$R_1 = \frac{W_P}{2}\left(1 - \frac{X_G}{r}\right)$$

Friction force, F_F: [1]

$$F_F = \frac{\frac{R_M}{2} - R_1 + F_W\left(\tan\Omega - \frac{Z_P - Z_o}{s}\right) + F_T\left(\tan\Omega - \frac{Z_G - Z_o}{s}\right)}{\tan\Omega + \frac{Z_o}{s}}$$

Main gear reaction, R_2:

---

[1] The DDS 130 – 2 (NAVSEA, 1984) equation for F_F is incorrect, and has been corrected here.

$$R_2 = \frac{R_M}{2} + \frac{F_W(Z_P - Z_o)}{s} + \frac{F_T(Z_G - Z_o)}{s} + \frac{F_F Z_o}{s}$$

Tiedown force, T:

$$T = \frac{F_W + F_T - F_F}{\cos\Omega}$$

The critical gear load will generally be the main gear reaction R_2. However, it is possible for R_A to govern, therefore, in the subsequent calculations use the larger value reaction.

Variation in Loading due to the Recovery Assist, Securing, and Traversing (RAST) System

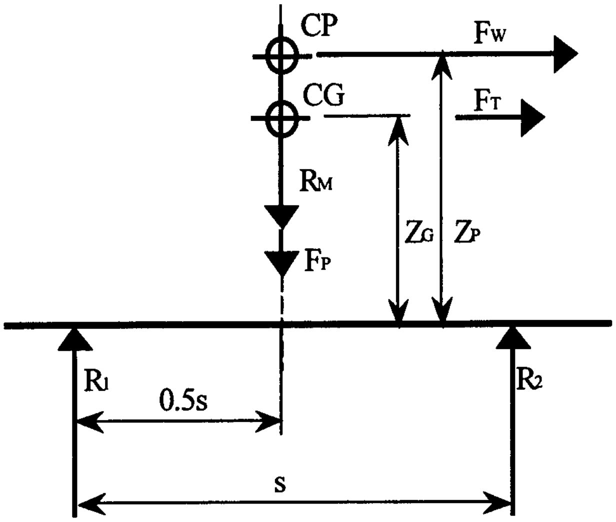
The system has a small effect on the gear reactions. The RAST system does not increase the calculated landing reactions. However, a vertical restraint on the helicopter by the system decreases the parking reactions. Parking in this context is the time between landing and take off.

Landing Loads

The RAST system itself tends to increase the landing loads, due to the cable haul down tension. However, landing loads do not exceed the nominal landing load, R_L, which the helicopter manufacturer provides. Therefore, there is no variation in landing load calculations for the RAST system.

Parking Loads

The parking condition includes the securing, traversing, and storage of the helicopter for ships with RAST systems. The probe holds the helicopter to the deck to resist the longitudinal ship motion force, F_L, the transverse ship motion force, F_T, and the wind force F_W. The probe acts as a vertical tiedown, F_P, applied at the centerline of the helicopter. Calculate the resulting gear reactions as follows: (Figures 1&3)



FP = probe force

Figure 3: Transverse Free-Body Diagram of Helicopter for RAST System

Maximum total main gear reaction, R_M, vertical force equilibrium:

$$R_M = F_D\left(1-\frac{X_G}{r}\right)$$

Maximum auxiliary gear reaction, R_A, vertical force equilibrium:

$$R_A = \frac{F_D X_G}{r}$$

Helicopter overturning moment, M:

$$M = F_W Z_P + F_T Z_G - \frac{R_M s}{2}$$

The same applies for the probe force F_P as for the tiedown force. If the helicopter has a positive overturning moment, then the probe force applies. If the overturning force is negative then the probe force is not effective. After calculating M, compute the two main gear reactions, which are different for the two conditions of $M \leq 0$ and $M > 0$.

No Overturning Moment, $M \leq 0$

If $M \leq 0$, then there is no probe force applied to the system, $F_P = 0$

Main gear reaction, R_2:

$$R_2 = \frac{R_M}{2} + \frac{F_W Z_P}{s} + \frac{F_T Z_G}{s}$$

Main gear reaction, R_1:

$$R_1 = R_M - R_2$$

Positive Overturning Moment, $M > 0$

If $M > 0$, then the probe force is applied to the system.

Main gear reaction, R_1:

$$R_1 = \frac{W_P}{2}\left(1 - \frac{X_G}{r}\right)$$

Probe force, F_P:

$$F_P = 2R_1 + \frac{2F_T Z_G}{s} + \frac{2F_W Z_P}{s} - R_M$$

Main gear reaction, R_2:

$$R_2 = \frac{R_M}{2} + \frac{F_P}{2} + \frac{F_T Z_G}{s} + \frac{F_W Z_P}{s}$$

Structural Framing of Flight Decks and Handling Areas

The structural framing of the flight deck and handling area on a US Navy ship is a continuously welded plate deck grillage. A flat plate is supported by multi-span stiffeners. Beams, girders, and/or bulkheads support the stiffeners at uniform positions. The framing is a grid system, so the deck plate acts as the top flange for the stiffeners, beams, and the girders. Thus, the deck structure is a statically indeterminate system. To account for the interaction effect of the members, the structural parameters of each member are adjusted by several coefficients. Each parameter is discussed in the Structural Analysis section.

The analysis methodology is valid only for plate-deck structures with plating less than one inch thick and flexible stiffener supports for longitudinally or transversely framed decks. Decks not meeting these criteria must be analyzed with the finite element method.

Generally, combatants are longitudinally stiffened; some auxiliaries are transversely stiffened. The supporting members perpendicular to the stiffeners are referred to as beams in this analysis. The following types of drawings are needed: inboard profile, compartment and access of the flight deck and hangar area, and the structural plan view for the flight deck and hangar area. Figures 4 – 8 are examples of the types of drawings required for the analysis. The example drawings shown are of the DDG 51 Class (NAVSEA, 1985).

Figure 4:	Inboard Profile of the ship's stern
Figure 5:	Compartment and Access of the flight deck and hangar area
Figure 6-8:	Structural Plans of the DDG 51 Class Main Deck

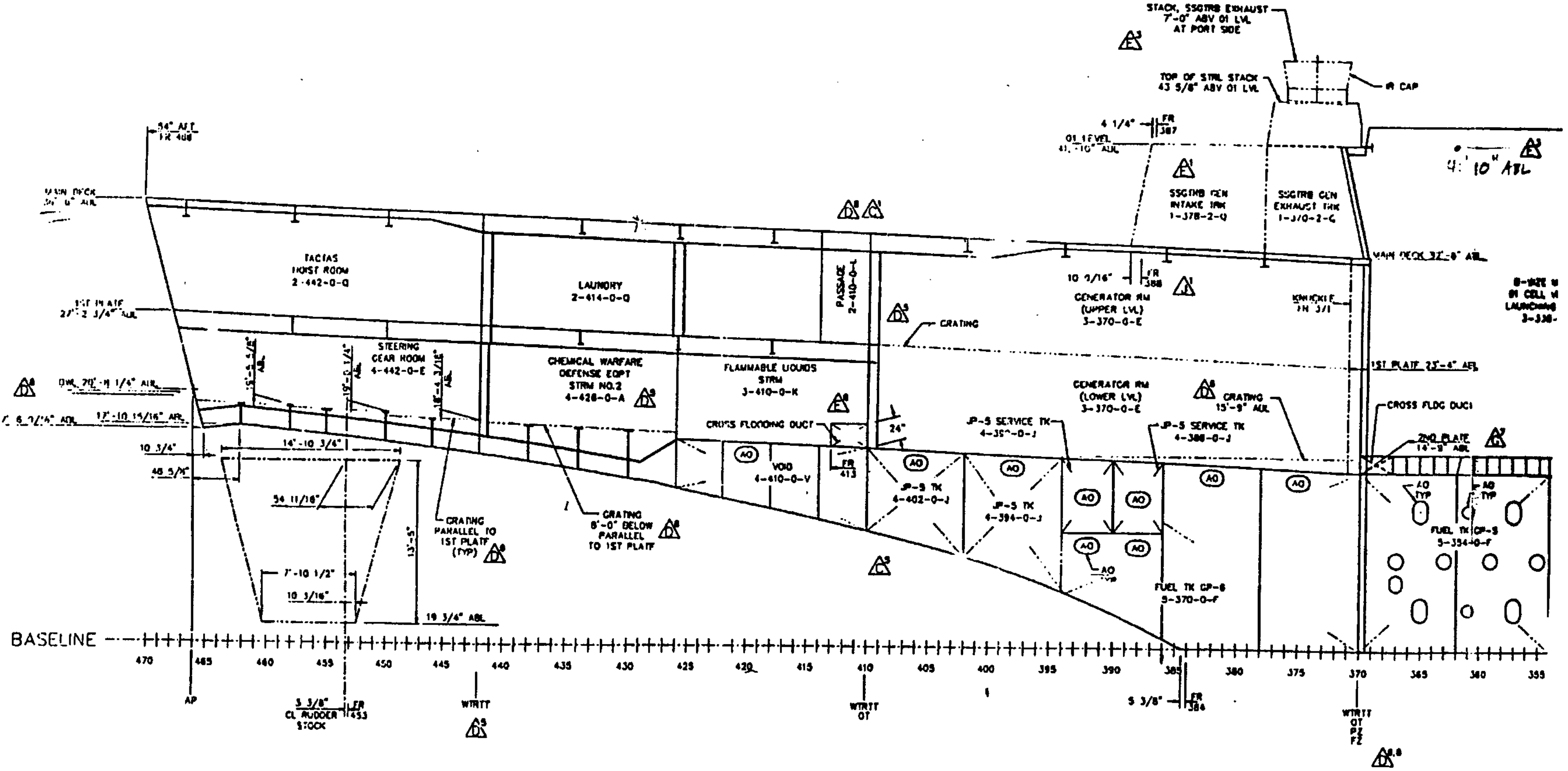


Figure 4. Inboard Profile Stern of Ship - NAVSEA Drawing 101-6219378

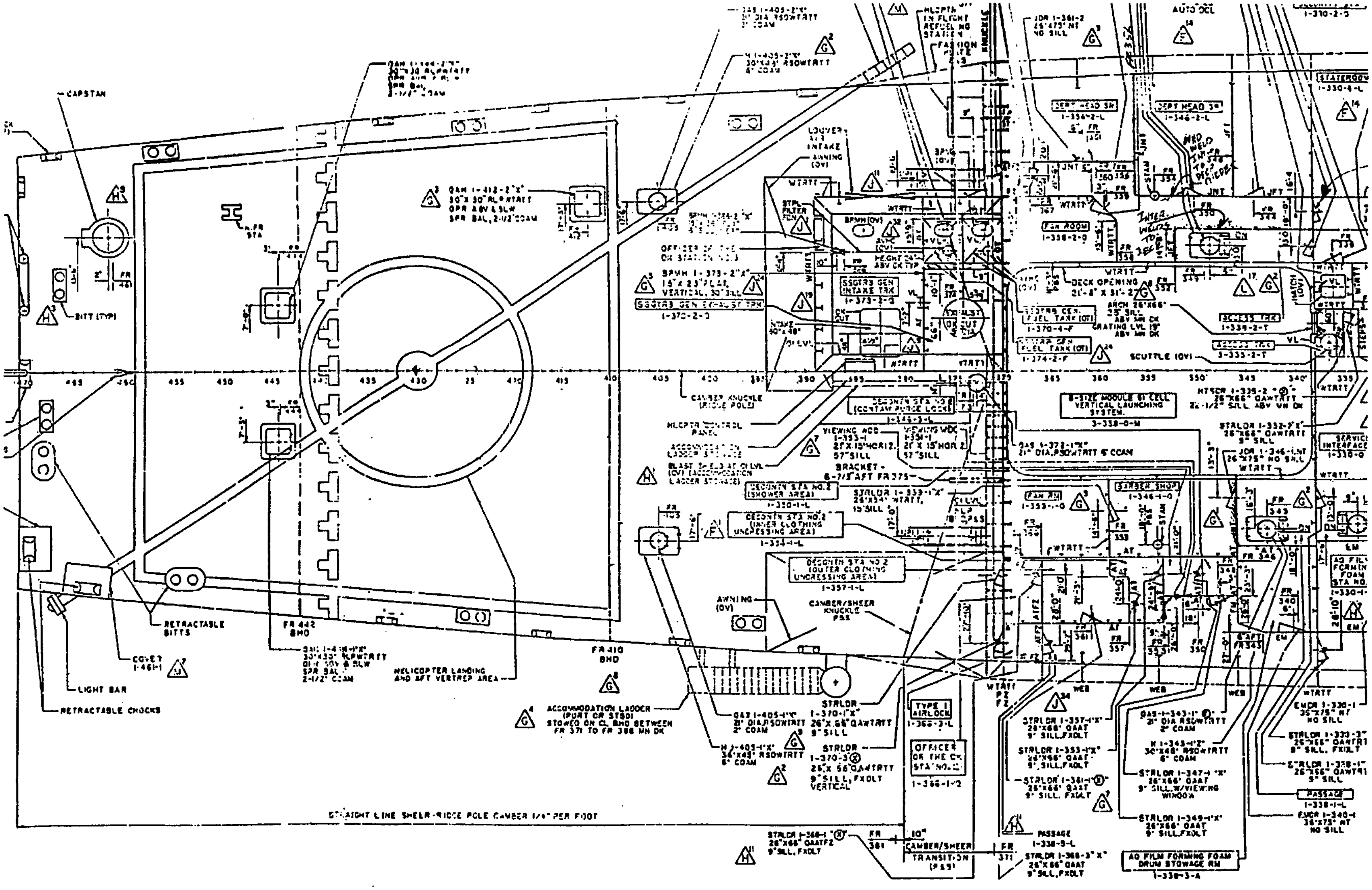


Figure 5. Compartment and Access of Handling Area, NAVSEA Drawing 101-6218623

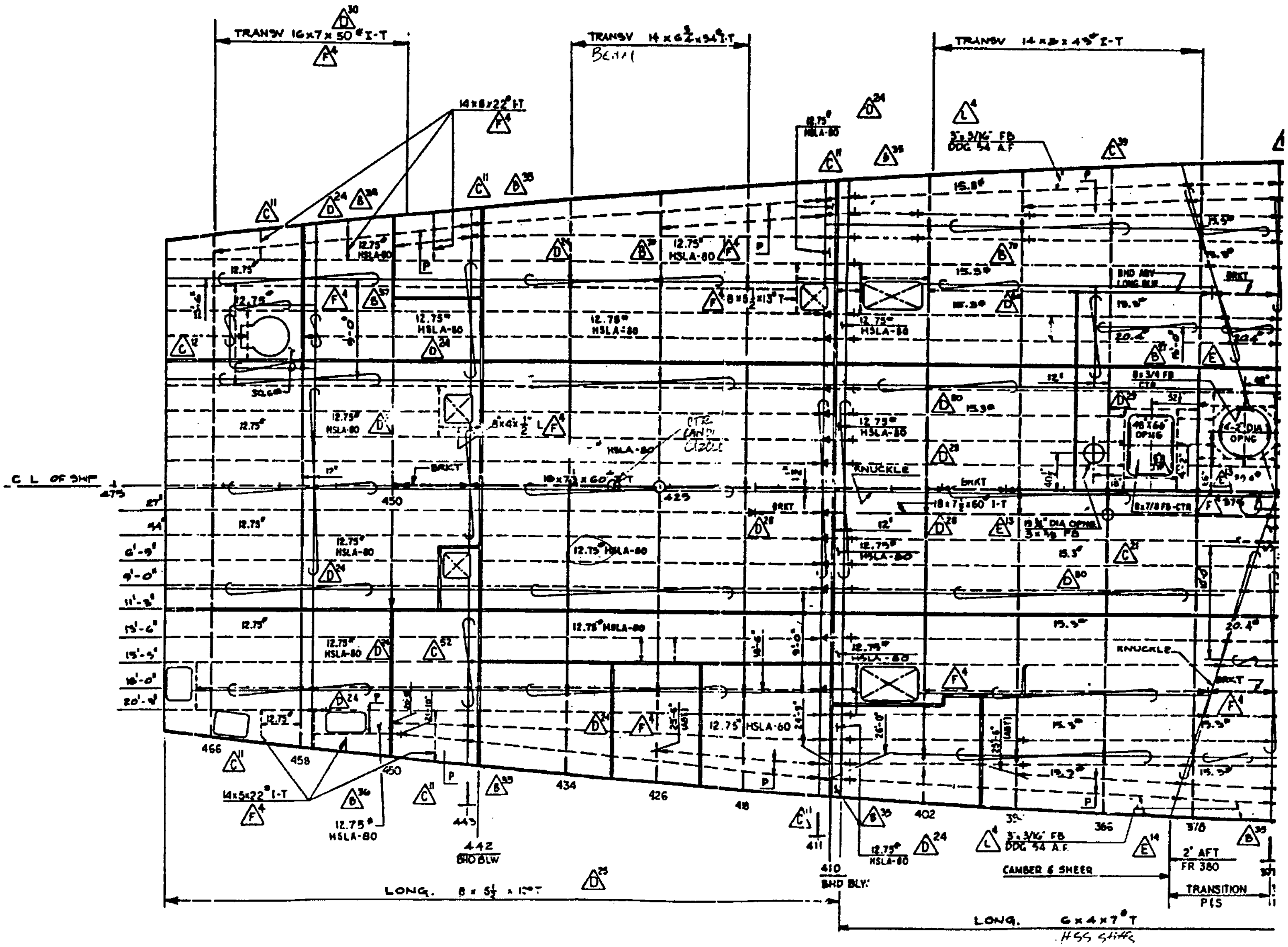


Figure 6. Structural Scantling Plan Stern to Frame 378, NAVSEA Drawing 100-6218844

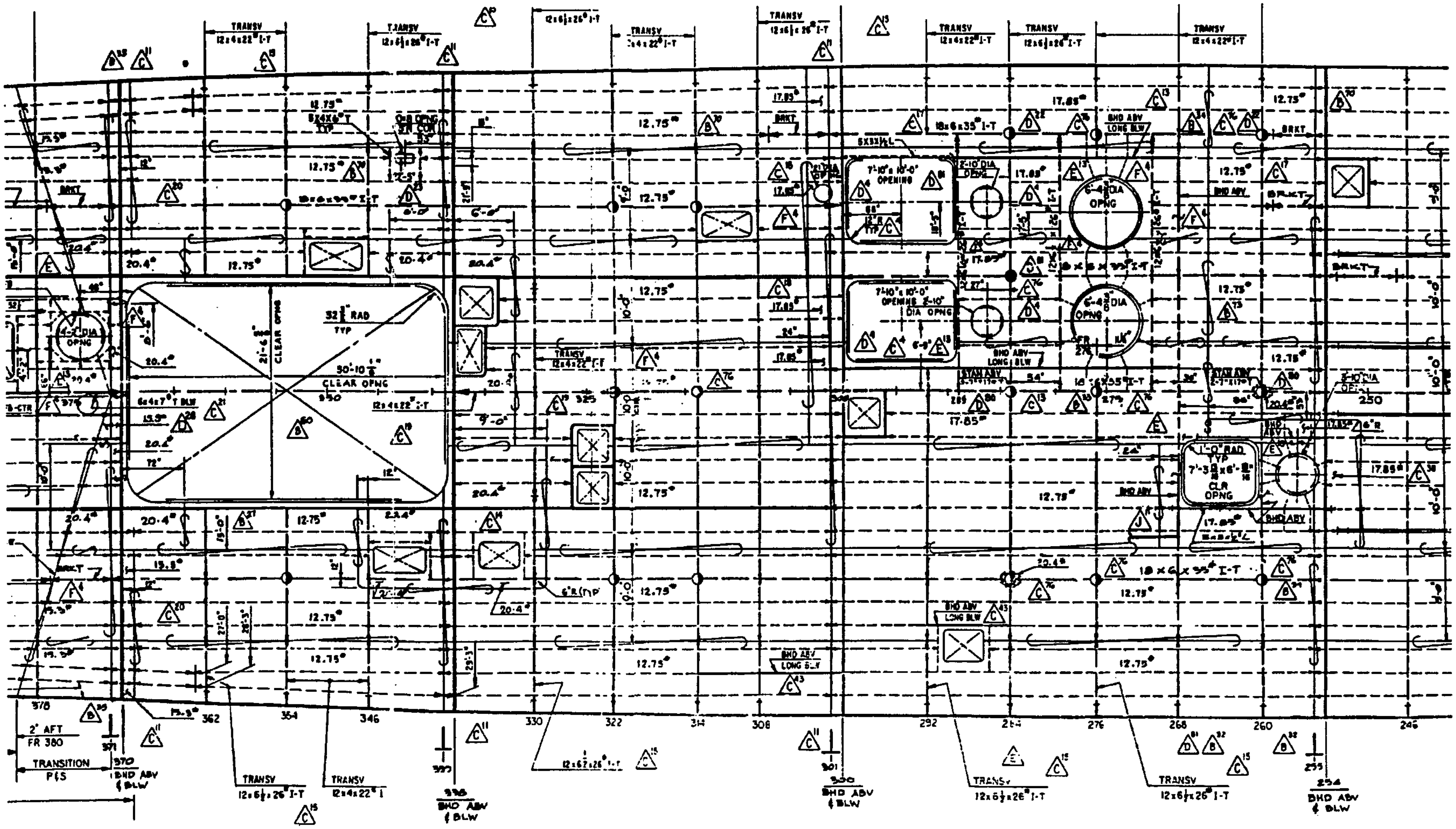


Figure 7. Structural Scantling Plan Frame 378 to Frame 246, NAVSEA Drawing 100-6218844

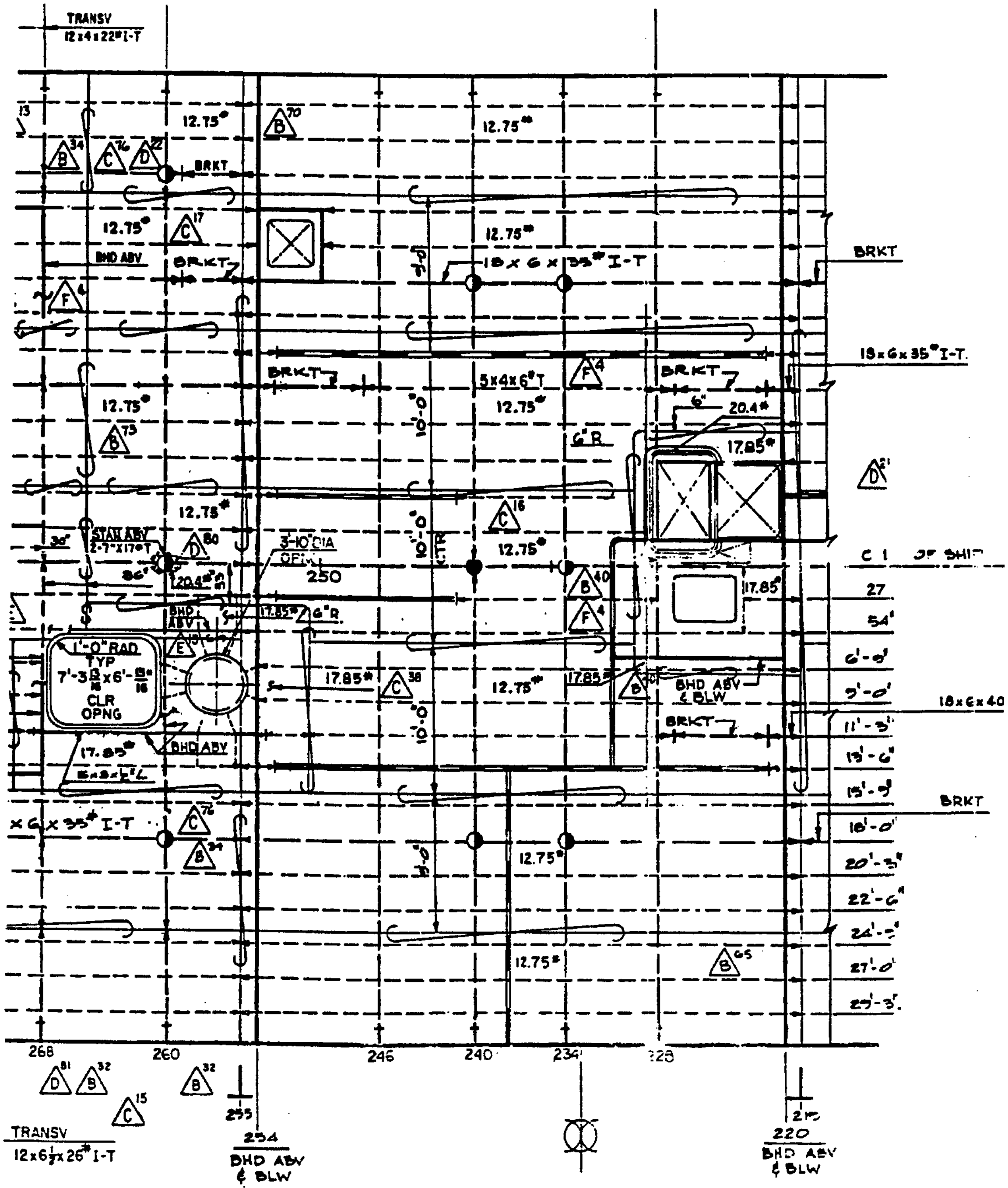


Figure 8. Structural Scantling Plan Frame 246 to Frame 220, NAVSEA Drawing 100-6218844

Design Criteria

For each material type used in ship construction, the ship specification will list its yield stress, F_y, and its maximum allowable working stress, F_b (sometimes referred to as F_{all}). These strength criteria can be found in *General Specifications for Ships of the U.S. Navy* Section 100 or in Section 9110-0 for older ships (NAVSEA).

The following analysis procedure considers the strength of the plating, stiffener bending, and stiffener shear separately. Each has separate strength criteria and parameters, which are applied in the analysis. The stress analysis is only performed on the plating and stiffeners. Since it has the smaller section properties only the stiffener is analyzed. If the stiffener passes, then logically the heavier transverse beam will also pass. If the stiffener fails, then there would be no need to check the transverse beam. Therefore, the supporting beams, girders, stanchions, and/or bulkheads are not analyzed specifically in this procedure.

Plating Strength

The allowable stress levels for the plating depend upon the loading condition, the sea condition, and the probability of occurrence. The calculated plating stress, f_P, must be less than or equal to the designated allowable stress level for each condition, as follows:

During storm seas, severe ship motions are assumed for parking loads, but these loads are infrequent. The deck plating allowable stress level for storm sea parking can be taken as the welded yield strength of the material, F_Y.

f_P (σ calculated) $\leq$ F_Y (yield stress)

For landing and moderate sea parking, which are the most common and frequent loads, the allowable stress level for plating is the allowable working stress of the material, F_b.

f_P (σ calculated) $\leq$ F_b (allowable working stress)

For ships using a RAST system, the allowable plating stress is the allowable working stress of the material, F_b. This applies to both longitudinal and athwartship loading and both sea conditions.

f_P (σ calculated) $\leq$ F_b (allowable working stress)

Stiffener Bending Strength

The allowable bending stress level for the stiffeners is the allowable working strength of the material. The calculated bending stress in the stiffener, f_{SB}, must be less than or equal to this.

f_{SB} (σ calculated) $\leq$ F_b (allowable working stress)

Stiffener Shear Strength

The allowable shear stress level for the stiffeners is sixty percent of the allowable working strength of the material. The calculated shear stress in the stiffener, f_{SV}, must be less than or equal to this.

f_{SV} (σ calculated) $\leq$ $0.6 \times F_b$ (60% of the allowable working stress)

Wheel Load Distribution

General Description of Tire Load Distribution

The loads applied to the flight deck structure are the calculated gear reactions for the landing and parking load conditions. How these reactions are then applies to the deck depends on the tire footprint size and the orientation of the aircraft to the ship. The load distributes uniformly over the estimated contact area between the tire and the deck. The contact area or tire footprint size is interpolated from a table provided by the helicopter manufacturer. The table values include load magnitude and tire characteristic effects. The tire characteristic parameters include the number of wheels per gear, the actual physical tire size, the type of tire, and tire pressure. How the load applies and distributes to the structure also depends on the aircraft orientation with respect to the ship structure.

Tire Footprint Size

Tire contact area depends on the gear load R, the number of wheels per gear, and the physical tire properties. Calculate the tire load P_T by dividing the gear load R by the number of wheels per gear. The tire load P_T calculation is used only for the footprint size.

Single wheeled gear:

$P_T = R$

Dual wheeled gear:

$P_T = \frac{1}{2} R$

The footprint size determined from P_T is a rectangular area of uniform pressure, with length A and width B (Figure 9). The manufacturer combines the tire characteristics and presents the load varying dimensions in a footprint-loading table (see below). Dimensions A and B can be linearly interpolated from this table.

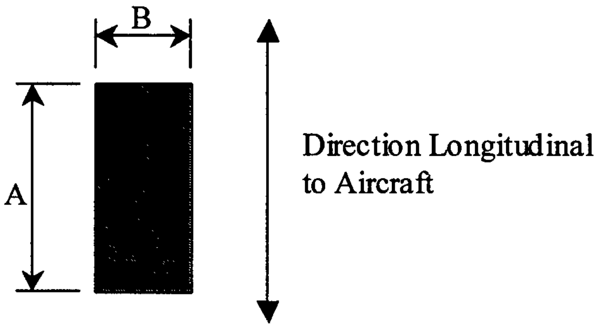


Figure 9: Tire Footprint

Table 2: Tire Footprint Load Table

P_T	A	B
P_{T1}	A_1	B_1
P_{T2}	A_2	B_2

Calculate the footprint dimensions with the following equations:

$$A = A_1 + \left(\frac{A_2 - A_1}{P_{T2} - P_{T1}} \right) (P_T - P_{T1})$$

$$B = B_1 + \left(\frac{B_2 - B_1}{P_{T2} - P_{T1}} \right) (P_T - P_{T1})$$

The manufacturer also provides a tire-bottoming load, P_b. When the tire load P_T reaches the bottoming load, P_b, the footprint flattens to the maximum dimensions A and B. At loads greater than and equal to P_b, the footprint dimensions A and B are equal to the maximum dimensions at tire bottoming. Numerically stated:

If $P_T \geq P_b$, then $A = A(P_b)$ and $B = B(P_b)$

The following example shows how to determine the tire footprint dimensions A and B graphically.

Example:
$P_b = 11.0$ kips

Table 3: Provided Tire Footprint Load Data

P_T	A	B
5	6	4.5
9	8	5

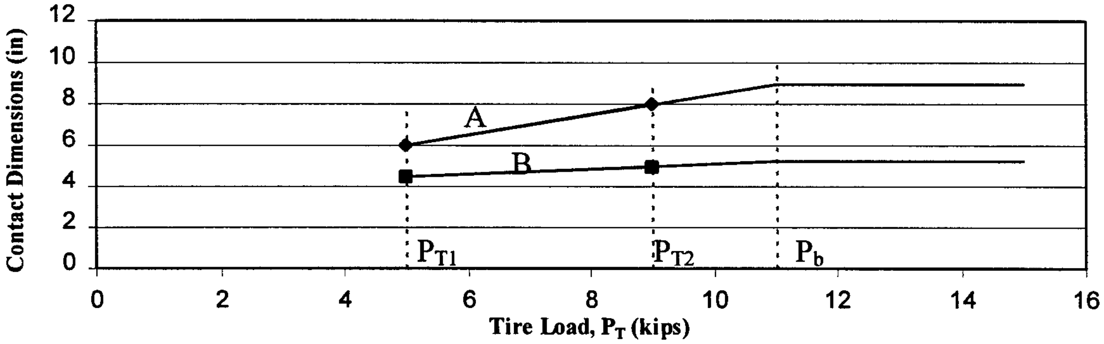


Figure 10: Graphical Illustration of Tire Load

Loading Variations due to Orientation

How the tire loads apply to the structure, depend on the orientation of the aircraft with respect to the ship's structure. After calculating the footprint dimensions A and B, orient the dimensions with respect to the structural framing. Tire footprint dimensions are reoriented to patch load dimensions (Figures 11-14). Patch load dimensions are with respect to the stiffeners.

A	length of tire footprint (in)
A'	length of tire parallel to the stiffeners (in)
B	width of tire footprint (in)
B'	width of tire perpendicular to the stiffeners (in)
c	dual wheel spacing, center to center[2] (in)

The gear load reaction R modifies to a patch load, P. If the gear is aligned with the stiffeners, then the patch load P is equal to the gear load reaction R divided by the number of wheels per gear. If the gear is perpendicular to the stiffeners, then the patch load will equal the gear reaction, R.

Aircraft aligned parallel with the stiffeners:

$A' = A$
$B' = B$

For a single wheeled gear, Condition A (Figure 11)
$P = R = P_T$

For a dual wheeled gear, Condition B (Figure 12)
$P = \frac{1}{2} R = P_T$

Aircraft aligned perpendicular to the stiffeners:

$B' = A$
$P = R$

For a single wheeled gear, Condition C (Figure 13)
$A' = B$
$P = R = P_T$

For a dual wheeled gear, Condition D (Figure 14)
$A' = c + B$
$P = R = 2 P_T$

In the dual wheel perpendicular case (Condition D), the patch load, P, does not equal the tire load P_T because both wheels are sitting on the stiffener and causing a combined loading. The patch load, P, is therefore equal to the total gear reaction, R, acting over the total length c + B.[3]

---

[2] The annotation 'c' is a simplified notation for the DDS 130-2 notation of b': the center-to-center dual tire spacing and b'': the center-to-center dual patch spacing.

[3] This is a very close approximation for maximum loading in the center of the panel for the plating stress calculation.

$A' = A$
$B' = B$
$P = P_t = R$
Single Tire

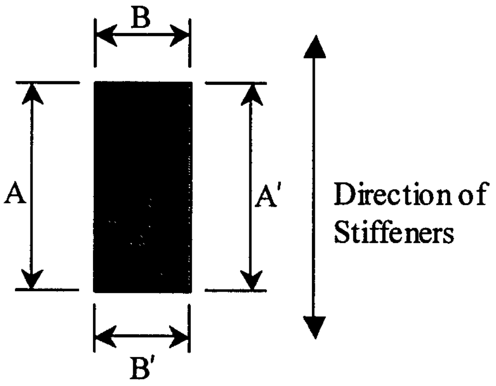


Figure 11: Patch Load Dimensions, Condition A

$A' = A$
$B' = B$
$P = P_t = R/2$
Dual Tire

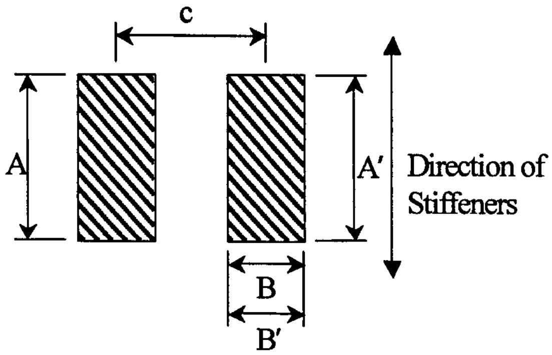


Figure 12: Patch Load Dimensions, Condition B

$A' = B$
$B' = A$
$P = P_t = R$
Single Tire

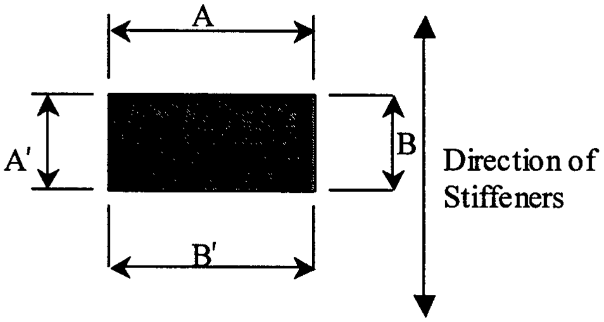


Figure 13: Patch Load Dimensions, Condition C

$A' = B + c$
$B' = A$
$P_t = R/2$
$P = R$
Dual Tire

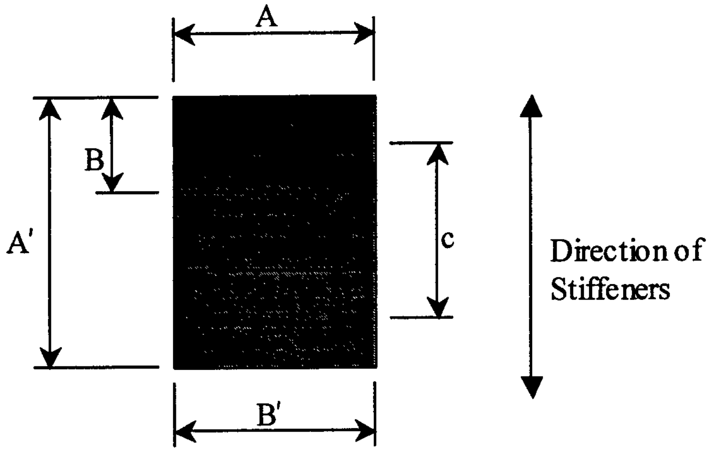


Figure 14: Patch Load Dimensions, Condition D

Structural Analysis

The deck structure is an indeterminate structure with continuous welds. Therefore, to account for these effects several parameters and factors are used. The plating analysis incorporates localized plasticity, membrane effects, and makes use of simplified approximations for the elastic-plastic behavior. The longitudinal stiffener analysis incorporates the transverse beam flexibility effects and grillage effects. Based on strip theory the approach uses design curves and influence lines extensively. Only the governing load placement of the helicopter gears is used to determine the maximum stress in the deck plating and longitudinal stiffeners.

Since, the stiffener has smaller section properties than the beam, perform the stress analysis on only the stiffener and plate. If the stiffener passes, then logically the heavier transverse beam also passes. The supporting beams, girders, stanchions, and/or bulkheads are not analyzed specifically in this procedure, but should be checked.

Structural Parameters

The structural parameters affecting the analysis include member and geometric characteristics. The member properties for the stiffener and beam take into account an effective width of the deck plate. The analysis assumes a uniform grillage arrangement, in which the supports are equally spaced and the members are uniformly sized. If this is not the case for the structure, it is recommended that a finite element analysis be performed.

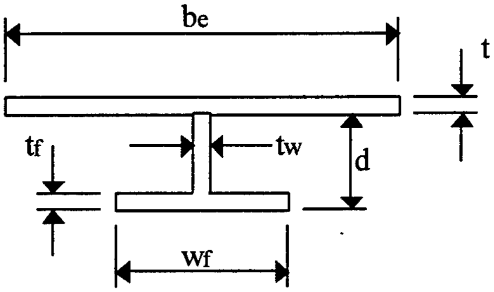
The properties of the stiffeners, beams, and girders are those of the actual member itself plus the effective width of the deck plating. The deck plating acts as the upper flange. The effective breath of the deck plating, b_e, is the minimum value of the following relationships: plate thickness t and material properties, one third the span length L_s, or stiffener spacing b.

$$b_e = \left\{ \begin{array}{c} 2t\sqrt{\dfrac{E}{F_y}} \\ \frac{1}{3} L_s \\ b \end{array} \right\}, \text{ minimum value}$$

The combined properties of the member and associated plating can be determined by hand calculation or from standard combined stiffener and plate property table listings, see *Properties of Steel Shapes, and Plate – Beam Combinations used in Shipbuilding* (NAVSEA). Figure 15 defines graphically the annotation of the section dimensions. The following section properties are required for the analysis:

Area	area of stiffener or beam (in^2)
A_s	shear area of stiffener or beam (in^2)
b	stiffener spacing (in)
I_s	stiffener moment of inertia (in^4)
I_b	beam moment of inertia (in^4)
L_s	length of a stiffener span (in)
L_b	length of a beam span (in)
n	number of spans between vertically rigid ship components (bulkheads, sideshell, etc.)
SM_{min}	minimum section modulus (in^3)
w_s	weight per foot of the stiffener (lb/ft)
w_b	weight per foot of the beam (lb/ft)
w_p	weight per foot of the plating (lb/ft)

The minimum section modulus is normally the section modulus to the flange.



b_e	effective width of plating (in)
d	depth of stiffener (in)
t	thickness of deck plating (in)
t_f	thickness of flange (in)
t_w	thickness of web (in)
w_f	width of bottom flange (in)

Figure 15: Combined Stiffener and Plate Section

This procedure is applicable to longitudinally and transversely framed decks. Note that the term “stiffener” refers to the smallest structural stiffener in the deck, usually the longitudinal. "Beams" support the stiffeners and normally span transversely. "Girders" are very deep members.

It is important to remember the method presented here assumes a uniform grillage arrangement and the stiffeners are assumed to be continuous, uniform-size beams. The spacing of the stiffeners and their supports are also assumed to be consistent. This procedure is applicable to longitudinally and transversely framed decks. When the structure of the deck does not meet these characteristics, then perform a finite element analysis of the deck using any commercially accepted finite element program. See the section Finite Element Modeling for modeling suggestions.

Primary Stress

Primary stress, σ_{PR}, is the maximum resulting stress on the ship structure due to the largest possible global bending of the ship hull from wave action. This stress only applies to strength decks, those decks contributing to the hull strength. In plating and stiffener design, add the primary stress to the longitudinal stress component of the member. Section 100 of the ship specifications lists the primary stress and explains how this stress distributes along the ship length. For each location analyzed the primary stress at that location must be determined, including locations on non-strength decks. The percentage of primary stress values at different loading conditions for strength decks are as shown in Table 4.

Table 4: Percentage of Design Primary Stress for Strength Decks

Loading Condition	Percent of Design Primary
Storm Sea Parking	100
Moderate Sea Parking	50
Landing	0

Deck Plating Analysis

The plating analysis is a simplified approach to the elastic-plastic behavior theory. The procedure uses the elastic-plastic behavior of the plating by taking advantage of the reserve energy absorption capability of the plate deck structure over that determined by the first order flexural theory. Based on Navy experience, permanent set is allowed to a degree. The parameters and strength values were empirically developed. *Design of Deck Structures under Wheel Loads* discusses their development (RINA, 1980). The load applied to the plating panel is the patch load, P, determined in "Wheel Load Distribution." The maximum stress condition is when the patch load is applied to the center of the plating panel. Furthermore, the maximum stress is in the direction of the plate's transverse or shorter dimension. Stiffeners and beams support the plating on all sides.

First, determine the non-dimensionalized plate bending moment, C_1, by the following equations. This parameter serves to quantify the plating bending moment as a function of the patch load size in relation to the stiffener spacing, b. Since the plating stress is always greater in the direction of the shorter span, the stiffener spacing, b, is the non-dimensionalizing parameter.

$$C_1 = \frac{0.25 - 0.125\left(\frac{B'}{b}\right)}{0.94 + 0.45\left(\frac{A'}{b}\right)} - \frac{0.079 - 0.026\left(\frac{B'}{b}\right)^2}{1.75 + 0.15\left(\frac{A'}{b}\right)^2}, \text{ when } \frac{A'}{b} \leq 0.5$$

$$C_1 = \frac{0.25 - 0.125\left(\frac{B'}{b}\right)}{\frac{A'}{b} + \frac{0.6}{\frac{A'}{b} + 0.4}} - \frac{0.079 - 0.026\left(\frac{B'}{b}\right)^2}{1.75 + 0.15\left(\frac{A'}{b}\right)^2}, \text{ when } \frac{A'}{b} > 0.5$$

Determine the ratios B′/b and c/b, then the dual patch equivalent load factor for plating, Ψ, from Figure 16. Note that for single patches Ψ = 1.0

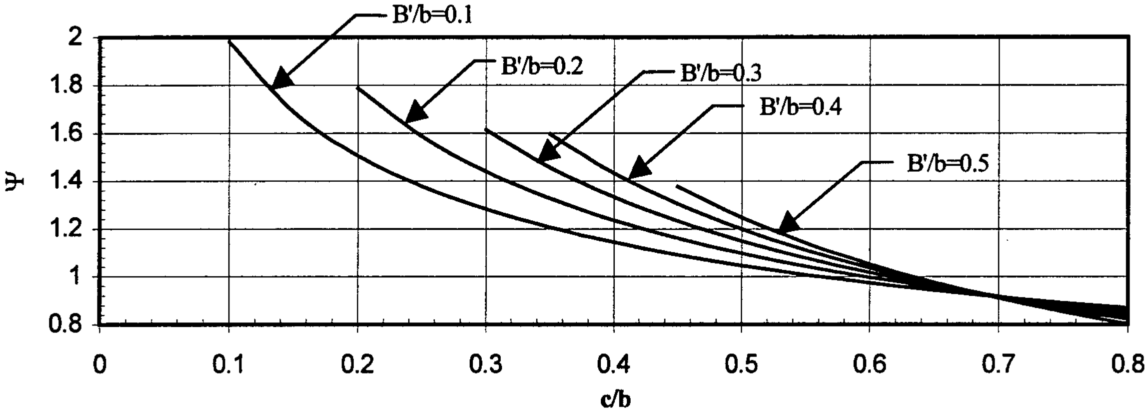


Figure 16: Dual Patch Equivalent Load Factor for Plating

A deck function coefficient, C_0, provides a relationship between allowable permanent set, load probability, and deck function. Deck function describes the deck's contribution to the hull girder strength and the type of aircraft operations performed. This parameter developed by NAVSEA uses empirical data based on Fleet observations. The C_0 factor lowers the plating stress to an artificial value, which effectively allows permanent set. Table 5 lists the deck function C_0 for particular sea conditions and deck strengths. Helicopter operations are considered low-speed handling. The uppermost strength deck is the ship's weather deck.

Table 5: Deck Function, C_0, for Steel or Aluminum

Deck Function	**Landing and Moderate Sea Parking**	**Storm Sea Parking**
Uppermost strength deck high speed rolling of aircraft	2.0	1.7
Uppermost strength deck low speed handling of aircraft	3.4	2.8
Non-uppermost strength deck high speed rolling of aircraft	3.4	2.8
Non-uppermost strength deck low speed handling of aircraft	4.2	3.5

The maximum bending stress is then:

$$f_p = \frac{6C_1P\Psi}{C_ot^2},$$

where

P	patch load (kips)
t	plating thickness (in)

If the maximum stress in the plate is in its transverse direction for a longitudinally stiffened deck, the primary stress is not included. However, for transversely stiffened decks subject to parking loads, the appropriate primary stress is combined with the calculated plating stress for parking loads.

Determine the required plating thickness, $t_{req'd}$ by the following equation:

$$t_{req'd} = \sqrt{\frac{6C_1P\Psi}{C_of_P}},$$

where f_P is the allowable plating stress for the various conditions defined in the "Design Criteria" section for plating strength.

Stiffener Analysis

The stiffener analysis incorporates grillage effects. For regular structural scantlings, the procedure is based on strip theory and the use of influence lines. Acting as continuous members, the beams elastically support the stiffeners, carry the load to the supports, and deflect proportionally. This procedure is applicable to both longitudinal and transverse framing. Furthermore, this analysis determines the maximum bending moment and shear in a stiffener for a single-patch or a dual-patch loading. The procedure, strength values, and parameters are based on *Design Manual for Orthotropic Steel Plate Deck Bridges* (AISC, 1963).

Effective Span Lengths

The stiffeners and beams are designed as continuous span members. The effective span length factor, e_s or e_b, is a function of the number of spans the member extends between vertically rigid ship components, such as bulkheads or the side shell. The calculation of vertical relative rigidity between plating and stiffener and between stiffener and beam uses these factors.

e_s = effective span length factor of the stiffener
e_b = effective span length factor of the beam

Table 6 lists the effective span length factors.

Table 6: Effective Span Factor

Number of spans	e_s or e_b
1	1.0
2	0.842
3	0.700
4	0.692
5 or more	0.684

Maximum Stiffener Bending Moment and Stress

When the patch load is applied directly on the stiffener at the mid-span, the maximum stiffener bending stress occurs. The maximum moment is the summation of: (1) the live load moment, M_0, which assumes rigid end supports, (2) the added moment due to flexibility of the beam supports, M_C, and (3) the moment due to the dead load, M_D. The load can be a single or dual patch load as determined in "Wheel Load Distribution." Several factors account for the structural member interaction and help distribute the load.

Apply the patch width load distribution factor, ϕ_1, to account for the distribution effects of the patch width, B′. Calculate B′/b and use Figure 17 to determine ϕ_1.

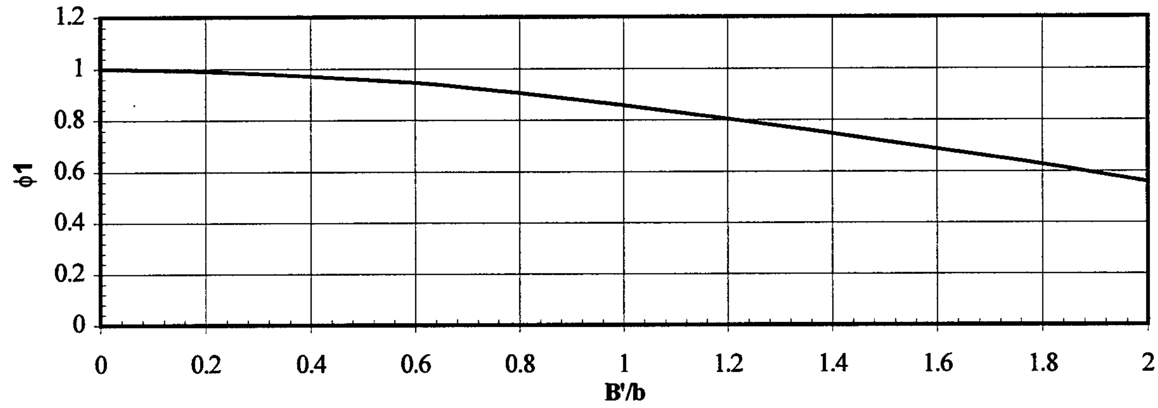


Figure 17: Patch Width Load Distribution Factor

To account for the distribution effects of the plating, use the plating load distribution factor, ϕ_2. To determine ϕ_2 calculate the relative rigidity between the plating and the stiffener, γ_{PS}, then use Figure 18. The following equation calculates the relative rigidity, γ_{PS}:

$$\gamma_{PS} = \frac{(e_s L_s)^4 t^3}{3.49 b^3 \pi^4 I_s}$$

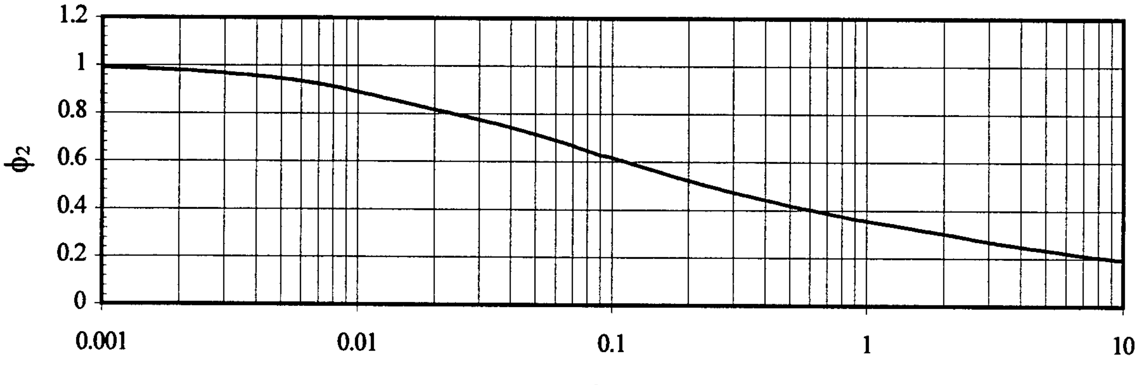
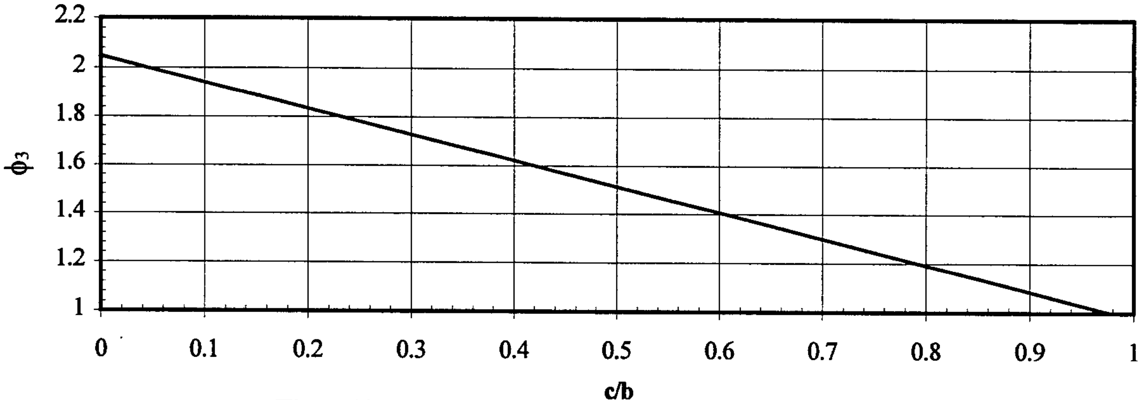


Figure 18: Plating Load Distribution Factor

To account for the combined effects of dual patches, use the dual patch equivalent load factor, ϕ_3. To determine ϕ_3 calculate c/b and use Figure 19. For a single patch: $\phi_3 = 1.0$.



Figue 19: Dual Patch Equivalent Load Factor for Stiffeners

The moment due to the live load over the rigid supports, M_o, is determined by using an influence line coefficient and then by applying the appropriate load factors. The influence line coefficient (M_o/PL_S) is for a moment at the mid-span of a continuous beam over equally spaced rigid supports with a patch load at the middle mid-span.

$$\frac{M_o}{PL_S} = 0.1708 - 0.125\left(\frac{A'}{L_S}\right) + 0.0264\left(\frac{A'}{L_S}\right)^2$$

Calculate the moment due to the live load over rigid supports, M_o, by applying the appropriate load factors to the influence line coefficient, using the following equation:

$$M_o = \left(\frac{M_o}{PL_S}\right)PL_S\phi_1\phi_2\phi_3$$

Since M_o represents the live load moment for fixed-end supports, the total live load moment is determined by adding an additional moment due to the flexibility of the beam supports M_C. If bulkheads are supporting stiffeners in lieu of beams, then the stiffener supports are rigid; then, $M_C = 0$.

Calculate the relative rigidity between the stiffener and beam, γ_{SB}, by the following equation:

$$\gamma_{SB} = \frac{(e_B L_B)^4 I_S}{0.684b(e_S L_S)^3 \pi^4 I_B}$$

The moment correction coefficient due to flexure of the beams, (M_C/RL_s), is obtained from Figure 20 using the relative rigidity, γ_{SB}.

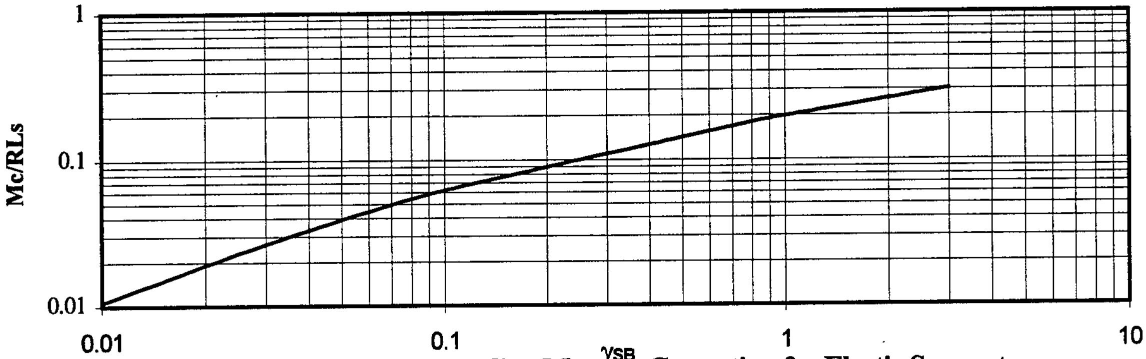


Figure 20: Stiffener Bending Moment Correction for Elastic Supports Coefficient

To account for the multiple gears, plating, and stiffener load distributions, assume a Fourier series component representation of the load on the transverse beam. This determines the moment in the stiffeners due to the beam flexure. The representation consists of a characteristic loading and a shape function.

R_o	beam characteristic load (kips/in)
B_o	characteristic load width (inch)
ϕ_4	beam loading coefficient

Based on the total gear load, the beam characteristic load, R_o, is as follows:

$$R_o = \begin{cases} \dfrac{R}{B'} & \text{single patch} \\ \dfrac{R}{(c + B')} & \text{dual patch} \end{cases}$$

Based on the total gear distribution, the characteristic load width, B_o, is as follows:

$$B_o = \begin{cases} \dfrac{B'}{2} & \text{single patch} \\ \tfrac{1}{2}\left(c + B'\right) & \text{dual patch} \end{cases}$$

Calculate the beam load coefficient, ϕ_4, using one of the following equations, depending on the aircraft's orientation to the stiffeners.

L_B	beam span length (in)
s	distance between R_1 and R_2 of main gear (in)

For the helicopter aligned with the stiffeners and where:

$$L_B \geq 1.5s$$

The beam loading coefficient is:

$$\phi_4 = \frac{4}{\pi}\cos\left(\frac{\pi s}{2L_B}\right)\sin\left(\frac{\pi B_o}{L_B}\right)\left(1 + \cos\left(\frac{\pi s}{2L_B}\right)\right)$$

For the helicopter aligned perpendicular to the stiffeners, and for the aircraft aligned with the stiffeners where:

$$L_B < 1.5s$$

The beam loading coefficient is

$$\phi_4 = \frac{4}{\pi}\sin\left(\frac{\pi B_o}{L_B}\right)$$

Finally, the moment due to the flexibility of the beam supports, M_C, is calculated by applying the appropriate load factors to (M_C/RL_s) using the following equation:

$$M_C = \left(\frac{M_C}{RL_S}\right)R_O b L_S \phi_4$$

The moment due to the dead weight of the plating and the stiffener, M_D, is the mid-span moment of a single span beam with fixed supports under the distributed load of it self-weight. Calculate the distributed load due to the weight of the plating and stiffener, w_D, using the following equation:

w_D	distributed load of the plating and stiffener weight (kips/inch)
w_s	weight of stiffener per foot (lbs/ft)
w_p	weight of plating per square foot (lbs/ft^2)

$$w_D = \frac{w_s + \frac{w_p b}{12}}{12000}$$

The moment due to the dead weight of the plating and stiffener, M_D, is then calculated using the following equation:

$$M_D = \frac{\eta_z w_D L_S{}^2}{12}$$

where η_z is the downward ship motion factor as defined in "Loading."

The maximum bending moment in the stiffener, M_S, is the sum of the moment components:

$$M_S = M_o + M_C + M_D$$

Depending whether or not the deck is a strength deck, the bending stress depends on one of the following equations. Section 100 of the individual ship specifications describes which decks of the hull contribute to its strength (NAVSEA). If the primary stress calculated for a non-strength deck is high, then use the f_{SB} equation for a strength deck.[4]

For landing or non-strength deck parking, calculate the bending stress f_{SB} as follows.

$$f_{SB} = \frac{M_S}{SM_{MIN}}$$

If the helicopter is on a strength deck, the stiffener stress must include the appropriate primary stress. Therefore, for strength deck parking, calculate the stiffener stress using the following equation:

$$f_{SB} = \frac{M_S}{SM_{MIN}} + \sigma_{PR}$$

For those decks using a RAST system for operations in heavier seas, it may be appropriate to include the primary stress for the landing condition. Depending upon the sea state specified in the vessel's detailed specifications for the flight operations, use an interpolated value of the

---

[4] This is a deviation from DDS 130-2, and is the result of discussions between NAVSEA, NSWCCD, and the original DDS authors.

primary stress. An estimate of the required section modulus, $SM_{REQ'D}$, results from the following equation:

$$SM_{REQ'D} = \frac{M_S}{(f_{SB} - \sigma_{PR})}$$

where f_{SB} is the allowable stiffener bending stress defined in the "Design Criteria" section for stiffener bending stress.

Maximum Stiffener Shear Force and Stress

The maximum shear force loading condition occurs when the patch load is adjacent to the stiffener support directly over the stiffener. Maximum shear force is the summation of: (1) the shear due to the live load, V_o, assuming the stiffener is a continuous beam on rigid supports, and (2) the shear due to the dead weight of the plating and stiffener, V_D.

The load applied to the stiffener is a single or dual patch load of length A′ (along the stiffener), width B′ (perpendicular to the stiffener), magnitude P, and dual patch spacing b′, as previously described.

To account for the distribution effects of the patch width, B′, use the patch width load distribution factor, ϕ_1. Use the dual patch equivalent load factor for stiffeners ϕ_3 to account for the combined effects of dual patches.

Determine the shear due to the live load over rigid supports, V_o, using the influence line coefficient (V_o/P) and the appropriate load factors. The influence line coefficient for the shear at the support of a continuous beam over equally spaced rigid supports for a patch load adjacent to the support is as follows:

$$\frac{Vo}{P} = 1 - 0.7321\left(\frac{A'}{L_S}\right)^2 + 0.2990\left(\frac{A'}{L_S}\right)^3$$

Calculate the shear V_o due to the live load over rigid supports by applying the appropriate load factors to the influence line coefficient:

$$V_O = \left(\frac{V_O}{P}\right)P\phi_1\phi_3$$

Calculate the shear V_D at the support of a single span beam due to the plating and stiffener self-weight w_D, as follows:

$$V_D = \frac{\eta_z w_D L_S}{2}$$

The maximum shear force in the stiffener, V_S, is the sum of these two components.

$V_S = V_o + V_D$

Calculate the shear stress by the following:

$$f_{SV} = \frac{V_S}{A_S}$$

An estimate of the required shear area, $A_{SREQ'D}$, is determined by:

$$A_{SREQ'D} = \frac{V_S}{f_{SV}}$$

where f_{SV} is the allowable shear stress defined in the "Design Criteria" section for stiffener shearing stress.

Beams, Girders, and Stanchions

Beams, girders, and stanchions supporting the aircraft handling decks must be designed to withstand the maximum bending, shear or compressive stress induced by the aircraft gear loads or any other loading requirements of the deck. The allowable stress levels for the beams, girders, and stanchions are as per the design criteria in the ship specifications. This analysis procedure does not calculate the stresses in these members. However, consider the beams and girders, when performing the analysis.

To analyze the beams, either a frame analysis or the method described herein may be used. If a frame analysis is chosen, the procedure can be simplified. Due to the relatively large span of the beams and girders, the consider gear load as a concentrated load, regardless of whether the gear has single or dual wheels. It is essential that the most critical loading condition be determined, since the aircraft could be at almost any location on the deck. For both beams and girders, use any acceptable linear analysis method such as moment distribution. The outlined procedure developed for the stiffener is applicable for a beam analysis. The parameters and strength values also apply to the beams and/or girders. Simply, consider the members as the continuous stiffeners supported by larger members running perpendicular to the beam and/or girder. Nevertheless, chose the method based on the structural geometry and engineering discretion.

Stanchions provide intermediate support for the beams or girders where their spans would otherwise be excessive. Likewise, where bulkheads support the deck stiffeners, beams, or girders, the vertical stiffeners under the beams act as a column. Determine the maximum reaction into the stanchion or bulkhead support, then use DDS 100-4 to determine the adequacy and/or required size of the member (NAVSEA, 1982).

Analytical Tools

Current Methods

The computation of the helicopter handling deck analysis and design can be carried out in three ways. The first method is by doing hand calculations for the method presented here. However, two computer methods can be used, either a finite element model analysis or the Excel spreadsheet developed by NAVSEA and revised by NSWCCD. The Excel spreadsheet follows the procedure prescribed by DDS 130-2.

Finite Element Modeling

Using any current finite element modeling (FEM) program, the analysis of a ship's handling deck can be accurately performed for deformations in the linear range. Determine the gear reactions and footprints using either the Excel spreadsheet or hand calculations. The finite element analysis (FEA) will not take into account permanent set allowed in the deck plating. This permanent set factor is not easily introduced into the FEM without using nonlinear analysis codes. Because the DDS 130-2 method allows permanent set, the FEA results for deck plating stress will not agree with the spreadsheet results. This is discussed in the "Recommendations" section.

Excel Spreadsheet

To aid in the analysis of the ship handling decks, NAVSEA developed a spreadsheet to run through the procedure outlined in DDS 130-2. This spreadsheet was updated in September 2000 by the author at the Naval Surface Warfare Center, Carderock Division. This updated spreadsheet still follows the DDS 130-2 procedure.

In order to use the spreadsheet, the user will need the ship and helicopter data described in the DDS. Data sheets used for gathering the input are supplied in Appendices A and B. The required input is highlighted in the color blue on the spreadsheet. An example of the use of the spreadsheet using the CH-60S helicopter on the DDG 51 Class flight deck is given in Appendix C.

Once the data are entered into the program, the results are displayed at the bottom of the spreadsheet in a table. For each required loading condition, the table lists the maximum gear reaction, maximum patch load, largest calculated stresses, and resulting factors of safety. The resulting stress and corresponding factor of safety is computed for plating stress, stiffener bending stress, and stiffener shear stress. If the factor of safety is less than one, then that component fails certification. If the factor is greater than one, then the component passes. All three components for all the applicable loading conditions must pass in order for the ship to be certified without restrictions.

Note: the spreadsheet has a few caveats in its analysis.

1. The spreadsheet only considers the largest gear reaction in its subsequent analysis. It does not calculate the stresses resulting from the other gear reactions. It is advised to check the other gear reactions for the possibility of causing a greater stress on the members other than the 'critical' gear reaction.

2. The spreadsheet does not check a specific location; it only analyzes the locations where the maximum stress condition is produced. However, several of the factors and equations developed in this procedure are specific for the maximum stress locations and are not applicable for specific locations other than at the assumed locations. For example, stiffener bending stress is a maximum at the stiffener mid-span. If specific spot locations must be considered, a FEA should be performed.

3. If the calculated main gear load equals the auxiliary gear load exactly, the spreadsheet defaults and uses the main gear reaction for remaining calculations. Depending upon the tire characteristics, the main gear reaction may not produce the governing stress condition for the helicopter.

4. If one gear reaction is exactly half the reaction of the other gear reaction, then the spreadsheet incorrectly calculates the remaining parameters.

5. The spreadsheet does not consider helicopters with skids, only wheeled gears.

For the present effort, these caveats were not addressed, since a total overhaul of the spreadsheet logic would be required. Moreover, it was sufficient to check these parameters by inspection during the certification of the Navy's ships for the newest helicopters, SH-60R and CH-60S.

Conclusion

Based upon past helicopter certifications, the method outlined by the DDS 130-2 is reliable. Most analysis cases are straight forward, and use of the DDS 130-2 procedure is adequate. For these cases, the NAVSEA spreadsheet provides the most efficient means to determine a ship's capability to operate with a specific helicopter. However, addition of the suggested revisions to the procedure would provide a more accurate and thorough analysis.

Recommendations

The procedure outlined in DDS 130-2 was developed in 1984. Several changes to the procedure could be made to ensure a more accurate and thorough analysis. The recommended revisions have been broken down by part.

Loading

Rolling of the ship is the only type of ship motion considered in the analysis. This motion causes the outboard main gear, R_2, to be much greater than the inboard main gear, R_1. This motion produces the greatest possible reaction. Such a reaction is suitable for a general analysis of the structure. However, if a structure requires a specific location to be analyzed or has varying members sizes, then reactions produced by other motion combinations should be computed and applied to the structure for analysis. For example, the inboard gear reaction R_1 is higher when only pitch and heave are present.

Wheel Load Distribution

The DDS determines the critical gear reaction based on the gear load, not the footprint. It suggests that the critical gear should be based on both, however this is not implemented in the procedure. Furthermore, patch sizes and loading reactions should be determined for all of the helicopter gears, with the maximum stresses tabulated.

Structural Analysis

The analysis only considers the locations which would produce the maximum stresses. If a specific location must be analyzed, then this procedure is not applicable. The equations used by the DDS were derived for determining the stresses at specific locations producing the greatest stress. A set of generalized equations should be developed for any location.

The analysis also accounts for permanent set in the plating using a C_o factor. However, no background is provided on how this factor was developed. Furthermore, the deck function coefficient decreases the calculated plating stress. When performing a finite element analysis, the stress values are not comparable to the spreadsheet values for plating stress. This factor needs modified to increase the capacity of the plating allowable stress while leaving the imposed stress unmodified.

Analysis of the Navy cruisers recently revealed a high primary stress in the 02 level. According to the DDS, primary stress need not be added to the stresses induced by helicopter wheel loads on a non-strength deck. However, discussions with NAVSEA and the DDS authors confirmed that this was written at a time when non-strength deck stresses were thought to be low. A caveat should be therefore be added to the DDS equation Q.1-17 to check if primary stress is high in this deck.

Analytical Tools

The current spreadsheet considers only straightforward cases. The spreadsheet should be implemented with the above suggested revisions. Also, the Excel Spreadsheet section makes note of further recommended revisions to the spreadsheet.

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Appendix A

HELICOPTER TYPE: ______________

WEIGHT (KIP):

W_M = ________

W_P = ________

CENTER OF GRAVITY (IN):

Z_G = ________

X_G = ________

TIEDOWN DATA:

STORM SEAS	MODERATE SEAS
Z_{TS} = ________	Z_{TM} = ________
Y_{TS} = ________	Y_{TM} = ________
$OMEGA_S$ = ________	$OMEGA_M$ = ________

SAIL AREA/CENTER:

STORM SEAS	MODERATE SEAS
a_{ss} = ________	a_{sm} = ________
Z_{PS} = ________	Z_{PM} = ________

GEAR SPACING (IN):

r = ________

s = ________

MAIN GEAR:

R = ________

Pb = ________

b' = ________

AUXILARY GEAR:

R = ________

Pb = ________

b' = ________

TIRE FOOTPRINT LOAD DATA:

MAIN GEAR

P_T (KIP)	A (IN)	B (IN)

AUXILARY GEAR

P_T (KIP)	A (IN)	B (IN)

Appendix B

SHIP HULL / CLASS:

SHIP MOTION CONTANTS

K1 =	____________	K5 =	____________X	K9 =	____________X
K2 =	____________X	K6 =	____________Y	K10 =	____________Y
K3 =	____________Z	K7 =	____________Z	K11 =	____________
K4 =		K8 =		K12 =	

STRUCTURAL PROPERTIES

DECK LOCATION:

	SPOT 1	SPOT2	SPOT3	SPOT4
NAME:				
X				
Y				
Z				
PLATE:				
Schedule				
t=				
wp=				
Fy=				
Fall=				
STIFFENER:				
Size				
ws=				
Fy=				
Fall=				
Area=				
As=				
I =				
SMmin=				
L=				
n =				
b=				
BEAM:				
Size				
ws=				
Fy=				
Fall=				
Area=				
As=				
I =				
SMmin=				
L=				
n =				

PRIMARY STRESS:

	STORM	STORM	STORM	STORM
Fpr =				

DECK FUNCTION:

	STORM	MOD.	STORM	MOD.	STORM	MOD.	STORM	MOD.
Co =								

Appendix C

HELICOPTER TYPE: CH-60S

WEIGHT (KIP):

W_M = 23.5 kip

W_P = 23.5 kip

CENTER OF GRAVITY (IN):

Z_G = 72.3 in

X_G = 65.4 in

TIEDOWN DATA:

STORM SEAS	MODERATE SEAS
Z_{TS} = 69.9 in	Z_{TM} = 32.4 in
Y_{TS} = 50.12 in	Y_{TM} = 9.62 in
$OMEGA_S$ = 45 deg	$OMEGA_M$ = 15 deg

SAIL AREA/CENTER:

STORM SEAS	MODERATE SEAS
a_{ss} = 410.0 ft^2	a_{sm} = 268 ft^2
Z_{PS} = 63 in	Z_{PM} = 76 in

GEAR SPACING (IN):

r = 347 in

s = 106 in

MAIN GEAR:

R = 27.88 kip

Pb = 30.4 kip

b' = 0.0 in

AUXILARY GEAR:

R = 7.29 kip

Pb = 13.0 kip

b' = 0.0 in

TIRE FOOTPRINT LOAD DATA:

MAIN GEAR

P_T (KIP)	A (IN)	B (IN)
10.0	16.5	9.1
27.88	20.5	10.0

AUXILARY GEAR

P_T (KIP)	A (IN)	B (IN)
4.24	9.8	5.3
7.2	12.0	6.1

SHIP HULL / CLASS:		DDG 51 Class			
SHIP MOTION CONTANTS					
K1 =	0.31000	K5 =	0.00130	K9 =	0.00263
K2 =	0.00028	K6 =	0.00300	K10 =	0.00560
K3 =	0.00263	K7 =	0.00560	K11 =	0.500
K4 =	0.50000	K8 =	1.40000	K12 =	0.500

STRUCTURAL PROPERTIES				
DECK LOCATION:	Main Deck			
	SPOT 1	SPOT2	SPOT3	SPOT4
NAME:	Centerline Fr 430 - TD			
X	193.00			
Y	0.00			
Z	10.97			
PLATE:	HY - 80			
Schedule	38t			
t=	0.313 in			
wp=	12.75 lbs/ft^2			
Fy=	80 ksi			
Fall=	50 ksi			
STIFFENER:	HSS, 50t			
Size	8x5.5x13# I-T			
ws=	12.83 lb/ft			
Fy=	51 ksi			
Fall=	40 ksi			
Area=	3.77 in^2			
As=	1.96 in^2			
I =	97.1 in^4			
SMmin=	17.8 in^3			
L=	96 in			
n =	4			
b=	27 in			
BEAM:	HSS, 50t			
Size	14x6.75x34# I-T			
ws=	23.54 lb/ft			
Fy=	51 ksi			
Fall=	40 ksi			
Area=	6.92 in^2			
As=	3.98 in^2			
I =	429.7 in^4			
SMmin=	52 in^3			
L=	135 in			
n =	4			
PRIMARY STRESS:				
	STORM	STORM	STORM	STORM
Fpr =	6.551 ksi			

DECK FUNCTION:								
	STORM	MOD.	STORM	MOD.	STORM	MOD.	STORM	MOD.
Co =	2.8	3.4						

CALCULATION OF HELODECK LOADS					DATE:
SHIP DATA:		**DDG51 FLT I**			
SPOT LOCATION:		**CENTERLINE FR 430**			
MOTION CONSTANTS (FOR DISTANCES IN FEET):					
K1 =	0.31000		K7 =	0.00560	Z
K2 =	0.00028	X	K8 =	1.40000	
K3 =	0.00263	Z	K9 =	0.00263	X
K4 =	0.50000		K10 =	0.00560	Y
K5 =	0.00130	X	* K11 =	0.50000	
K6 =	0.00300	Y	* K12 =	0.50000	
* MODERATE SEA CONSTANTS USUALLY K11=K12=0.50					
Spot location in the hanger? (No=0 / Yes=1)				0	
DECK LOCATION (FEET):					
X =	193.000	Y =	0.000		
Z =	10.970				
STRUCTURAL PROPERTIES					
PLATE:	HY-80				
t=	0.313	IN			
wp=	12.750	LBS/FT^2			
Fy=	80.000	KSI			
Fall=	52.000	KSI			
	STIFFENER:		BEAM:		
SIZE=	8x5.5x13#		14x6.75x34#I-T		
ws or wb=	12.830		23.540	LB/FT	
Fy=	51.000		51.000	KSI	
Fall=	40.000		40.000	KSI	
Area=	3.770		6.920	IN^2	
As=	1.960		3.980	IN^2	
I =	97.100		429.700	IN^4	
SMmin=	17.800		52.000	IN^3	
L=	96.000		135.000	IN	
n =	4		4		
es OR eb =	0.692		0.692		
b=	27.000	IN			
PRIMARY STRESS:					
	STORM SEAS			MODERATE SEAS	
Fpr=	6.551	KSI		3.276	KSI
DECK FUNCTION:					
	STORM SEAS			MODERATE SEAS	
CO =	2.800			3.400	
IS RAST USED (N=0/Y=1):			0		
MOTION FACTORS:					
	STORM SEAS			MODERATE SEAS	
	Nxs =	0.409		Nxm =	0.204
	Nys =	0.846		Nym =	0.423
	Nzs =	1.908		Nzm =	1.454
SHIP MOTION LOADS:					
	STORM SEAS			MODERATE SEAS	
	Fxs =	9.605		Fxm =	4.803
	Fys =	19.883		Fym =	9.941
	Fzs =	44.828		Fzm =	34.164
WIND LOADS:					
	STORM SEAS			MODERATE SEAS	
	Fws =	6.150		Fwm =	2.950
SHIP MOTION FORCES/GEAR REACTIONS:					
	LONGITUDINAL			ATHWARTSHIPS	
	STORM	MODERATE		STORM	MODERATE
Fl =	9.605	4.803		19.883	9.941
Ft =	19.883	9.941		9.605	4.803
Fd =	44.828	34.164		44.828	34.164
Rm =	38.381	28.726		40.522	29.797
Ra =	6.448	5.438		4.306	4.368
M =	-209.21	-617.88		-1065.76	-1046.15
UNSTABLE?	NO	NO		NO	NO
R1 =	1.974	5.829		10.054	9.869
R2 =	36.407	22.897		30.468	19.927
T OR FP =	0.000	0.000		0.000	0.000
R=	36.407	22.897		30.468	19.927
P=	36.407	22.897		30.468	19.927
TIRE LOAD:					
Pt=	36.407	22.897		30.468	19.927
TIRE DIMENSIONS:					
A=	21.064	19.385		21.064	18.721
B=	10.127	9.749		10.127	9.600

DDS 130-2 Revised Spreadsheet
Revised: September 2000
Flight Deck Loads and Stresses
Naval Surface Warfare Center
Carderock Division, Code 651
Suggestions for future modifications should be made to NSWCCD, Code 651.

3/15/01			**PARKING CALCULATIONS**			
HELO DATA:		**CH-60S**				
WEIGHT (KIP):						
Wm =	23.500					
Wp =	23.500					
CENTER OF GRAVITY (IN):						
Zg =	72.300					
Xg =	65.400					
TIEDOWN DATA:						
STORM SEAS			MODERATE SEAS			
Zts =	69.900	IN	Ztm =	32.400	IN	
Yts =	50.120	IN	Ytm =	9.620	IN	
OMEGAs =	45.000	DEG	OMEGAm =	15.000	DEG	
Zos =	67.020	IN	Zom =	20.776	IN	
SAIL AREA/CENTER:						
STORM SEAS			MODERATE SEAS			
As =	410.000	FT^2	Am =	393.300	FT^2	
Zps =	63.000	IN	Zpm =	63.000	IN	
GEAR SPACING (IN):						
r =	347.000					
s =	106.000					
MAIN GEAR						
R =	27.880	KIP				
Pb =	30.400	KIP				
b'=	0.000	IN				
AUXILIARY GEAR						
R =	7.290	KIP				
Pb =	13.000	KIP				
b'=	0.000	IN				
TIRE FOOTPRINT LOAD DATA						
MAIN GEAR			AUXILIARY GEAR			
Pt	A	B	Pt	A	B	
10.000	16.500	9.100	4.240	9.800	5.300	
27.880	20.500	10.000	7.200	12.000	6.100	
	TIRE FOOTPRINT EQUATIONS					
	MAIN GEAR		AUXILIARY GEAR			
	"A DIMENSION"		"A DIMENSION"			
	CONST =	14.263	CONST =	6.649		
	SLOPE =	0.224	SLOPE =	0.743		
	"B DIMENSION"		"B DIMENSION"			
	CONST =	8.597	CONST =	4.154		
	SLOPE =	0.050	SLOPE =	0.270		
	GEAR REACTION CALCULATIONS					
		LONGITUDINAL			ATHWARTSHIPS	
		STORM	MODERATE		STORM	MODERATE
	CONVENTIONAL					
	Rm =	38.381	28.726		40.522	29.797
	Ra =	10.450	7.440		12.592	8.510
	M=	-209.213	-617.876		-1065.760	-1046.149
IF M <= 0	R2 =	36.407	22.897		30.468	19.927
	R1 =	1.974	5.829		10.054	9.869
	Ff =	26.033	12.891		15.755	7.752
IF M >0	R1 =	9.535	9.535		9.535	9.535
	Ff =	21.400	4.902		16.073	8.472
	R2 =	33.478	21.331		30.669	20.068
		CHECK FOR CRITICAL GEAR LOADS (CONSISTENCY)				
	Rm =	38.381	28.726		40.522	29.797
	Ra =	6.448	5.438		4.306	4.368
	RAST					
	Rm =	36.379	27.725		36.379	27.725
	Ra =	8.449	6.439		8.449	6.439

SHIP DATA:		**DDG51 FLT I**			
SPOT LOCATION:		**CENTERLINE FR 430**			
ALIGNMENT WITH RESPECT TO STIFFENERS:					
	PARALLEL			PERPENDICULAR	
A' =	21.064	19.385		10.127	9.600
B'=	10.127	9.749		21.064	18.721
A'/b =	0.780	0.718		0.375	0.356
B'/b=	0.375	0.361		0.780	0.693
STIFFENER BENDING ANALYSIS:					
	LONGITUDINAL			ATHWARTSHIPS	
	STORM	MODERATE		STORM	MODERATE
$\Phi_{1/0}$ =	0.972	0.974		0.903	0.920
$\Phi_{1/1}$ =	0.009	0.008		0.043	0.035
γ_{PS} =			0.001		
Φ_2 =			0.992		
b'=	0.000	0.000		0.000	0.000
b'/b=	0.000	0.000		0.000	0.000
Φ_3 =	1.000	1.000		1.000	1.000
M_o/PL_s=	0.145	0.147		0.158	0.159
γ_{SB} =			0.033		
M_c/RL_s=			0.02835		
R_o=	3.595	2.349		1.446	1.064
B_o=	5.063	4.875		10.532	9.360
Φ_4 =	0.150	0.144		0.309	0.275
M_o=	487.836	311.662		414.019	276.944
M_c=	39.546	24.875		32.840	21.524
M_d=	5.069	3.863		5.069	3.863
M_s=	532.451	340.400		451.928	302.331
f_{sb}=	29.913	19.124		25.389	16.985
SM_{reqd}=	15.918	9.269		13.511	8.232
STIFFENER SHEAR FORCE ANALYSIS:					
V_o/P=	0.966	0.971		0.966	0.972
V_o=	34.179	21.652		26.570	17.828
V_d=	0.317	0.241		0.317	0.241
V_s=	34.495	21.894		26.887	18.069
f_{sv}=	17.600	11.170		13.718	9.219
As_{reqd}=	1.437	0.912		1.120	0.753
PLATE ANALYSIS:					
C_1=	0.11671311	0.122		0.102	0.111
ψ =	1.000	1.000		1.000	1.000
f_P=	92.942	50.279		67.876	39.803
t_{reqd}=	0.337	0.308		0.288	0.274

HELO DATA:		**CH-60S**		**PARKING CALCULATIONS**		
	RAST CONTINUED					
	M =	-103.142	-564.840		-846.196	-936.368
	IF M <= 0 Fp=0					
	R2 =	35.406	22.396		28.396	18.892
	R1 =	0.973	5.329		7.983	8.834
	IF M >0					
	R1 =	9.535	9.535		9.535	9.535
	FP =	17.125	8.414		3.105	1.404
	R2 =	43.969	26.603		29.949	19.593
		C1 CALCULATIONS				
		LONGITUDINAL			ATHWARTSHIPS	
		STORM	MODERATE		STORM	MODERATE
		0.116	0.121		0.102	0.111
		0.117	0.122		0.097	0.104

LOAD AND STRESS SUMMARY:

	LONGITUDINAL			ATHWARTSHIPS		
	STORM	MODERATE	LANDING	STORM	MODERATE	LANDING
R=	36.41	22.90	27.88	30.47	19.93	27.88
P=	36.41	22.90	27.88	30.47	19.93	27.88
fsb=	36.46	22.40	23.02	31.94	20.26	23.31
fsv=	17.60	11.17	13.51	13.72	9.22	12.61
f_P=	92.94	50.28	59.49	67.88	39.80	52.22
FS|fsb=	1.10	1.79	1.74	1.25	1.97	1.72
FS|fv=	1.36	2.15	1.78	1.75	2.60	1.90
FS|fp=	0.86	1.03	0.87	1.18	1.31	1.00

CALCULATION OF HELODECK LOADS **DATE:** **03/15/01** **LANDING CALCULATIONS**

SHIP DATA: **DDG51 FLT I**
SPOT LOCATION: **CENTERLINE FR 430**

MOTION CONSTANTS (FOR DISTANCES IN FEET):

K1 =	0.31000		K7 =	0.00560	Z
K2 =	0.00028	X	K8 =	1.40000	
K3 =	0.00263	Z	K9 =	0.00263	X
K4 =	0.50000		K10 =	0.00560	Y
K5 =	0.00130	X	* K11 =	0.50000	
K6 =	0.00300	Y	* K12 =	0.50000	

* MODERATE SEA CONSTANTS
USUALLY K11=K12=0.50

DECK LOCATION (FEET):
X = 193.000 Y = 0.000
Z = 10.970

STRUCTURAL PROPERTIES

PLATE:
t= 0.313 IN
wp= 12.750 LBS/FT^2
Fy= 80.000 KSI
Fall= 52.000 KSI

	STIFFENER:	BEAM:	
SIZE=	8x5.5x13#	14x6.75x34#I-T	
ws=	12.830	23.540	LB/FT
Fy=	51.000	51.000	KSI
Fall=	40.000	40.000	KSI
A=	3.770	6.920	IN^2
As=	1.960	3.980	IN^2
I =	97.100	429.700	IN^4
SMmin=	17.800	52.000	IN^3
L=	96.000	135.000	IN
n =	4.000	4.000	
es OR eb =	0.692	0.692	
b=	27.000 IN		

PRIMARY STRESS:

	STORM SEAS	MODERATE SEAS
Fpr=	6.551 KSI	3.276 KSI

DECK FUNCTION:

	STORM SEAS	MODERATE SEAS
CO =	XXXXXXXXX	3.400

IS RAST USED (N=0/Y=1): 0

MOTION FACTORS:

STORM SEAS		MODERATE SEAS	
Nxs =	0.409	Nxm =	0.204
Nys =	0.846	Nym =	0.423
Nzs =	1.908	Nzm =	1.454

AIRCRAFT DATA: **CH-60S**

WEIGHT (KIP):
Wm = 23.500
Wp = 23.500

CENTER OF GRAVITY (IN):
Zg = 72.300
Xg = 65.400

TIEDOWN DATA:

STORM SEAS			MODERATE SEAS		
Zts =	69.900	IN	Ztm =	32.400	IN
Yts =	50.120	IN	Ytm =	9.620	IN
OMEGAs =	45.000	DEG	OMEGAm =	15.000	DEG
Zos =	67.020	IN	Zom =	20.776	IN

SAIL AREA/CENTER:

STORM SEAS			MODERATE SEAS		
As =	410.000	FT^2	Am =	268.000	FT^2
Zps =	63.000	IN	Zpm =	76.000	IN

GEAR SPACING (IN):
r = 347.000
s = 106.000

MAIN GEAR
R = 27.880 KIP
Pb = 30.400 KIP
b'= 0.000 IN

AUXILIARY GEAR
R = 7.290 KIP
Pb = 13.000 KIP
b'= 0.000 IN

TIRE FOOTPRINT LOAD DATA

MAIN GEAR			AUXILIARY GEAR		
Pt	A	B	Pt	A	B
10.000	16.500	9.100	4.240	9.800	5.300
27.880	20.500	10.000	7.200	12.000	6.100

TIRE FOOTPRINT EQUATIONS

MAIN GEAR		AUXILIARY GEAR	
"A DIMENSION"		"A DIMENSION"	
CONST =	14.263	CONST =	6.649
SLOPE =	0.224	SLOPE =	0.743
"B DIMENSION"		"B DIMENSION"	
CONST =	8.597	CONST =	4.154
SLOPE =	0.050	SLOPE =	0.270

CALCULATION OF HELODECK LOADS
SHIP : DDG51 FLT I CENTERLINE FR 430

AIRCRAFT : CH-60S

LANDING CALCULATIONS
CH-60S

PAGE: 4/4

	LANDING		
	LONGITUDINAL		ATHWARTSHIPS
R=	27.880		27.880
P=	27.880		27.880
TIRE LOAD:			
Pt=	27.880		27.880
TIRE DIMENSIONS:			
A=	20.500		20.500
B=	10.000		10.000
ALIGNMENT WITH RESPECT TO STIFFENERS:			
	PARALLEL		PERPENDICULAR
A'=	20.500		10.000
B'=	10.000		20.500
A'/b =	0.759		0.370
B'/b=	0.370		0.759

	LANDING		
	LONGITUDINAL		ATHWARTSHIPS
$\Phi_{1/0}$ =	0.973		0.907
$\Phi_{1/1}$ =	0.008		0.041
γ_{PS} =		0.001	
Φ_2 =		0.992	
b^*=	0.000		0.000
b^*/b=	0.000		0.000
Φ_3 =	1.000		1.000
M_o/PL_s=	0.145		0.158
γ_{SB} =		0.033	
M_c/RL_s=		0.028	
R_o=	2.788		1.360
B_o=	5.000		10.250
Φ_4 =	0.148		0.301
M_o=	375.558		380.961
M_c=	30.285		30.067
M_d=	3.863		3.863
M_s=	409.706		414.891
f_{sb}=	23.017		23.308
SM_{reqd}=	12.249		12.404
STIFFENER SHEAR FORCE ANALYSIS:			
V_o/P=	0.967		0.967
V_o=	26.239		24.469
V_d=	0.241		0.241
V_s=	26.480		24.710
f_{sv}=	13.510		12.607
As_{reqd}=	1.103		1.030
PLATE ANALYSIS:			
C_1=	0.118		0.104
ψ =	1.000		1.000
f_P=	59.492		52.224
t_{reqd}=	0.335		0.314

C1 CALCULATIONS (FOR MODERATE SEAS)

LONGITUDINAL	ATHWARTSHIPS
0.118	0.104
0.118	0.099

LOAD AND STRESS SUMMARY:

	LANDING	
	LONGITUDINAL	ATHWARTSHIPS
R=	27.880	27.880
P=	27.880	27.880
fsb=	23.017	23.308
fsv=	13.510	12.607
fp=	59.492	52.224
FS|fsb=	1.738	1.716
FS|fv=	1.776	1.904
FS|fp=	0.874	0.996

Annotation and Definitions

A	-	contact length of tire	in
A'	-	patch length of loaded tire on deck, along stiffener	in
Area	-	area of stiffener or beam	in^2
A_s	-	shear area of member (depth of member x web thickness)	
$A_{s\ reqd}$	-	required shear area for stiffener	in^2
a_{ss}	-	sail area of helicopter in storm seas	in^2
a_{sm}	-	sail area of helicopter in moderate seas	in^2
B	-	contact width of tire	in
B'	-	patch width of loaded tire on deck, perpendicular to stiffener	in
B_o	-	beam characteristic load width	in
b	-	stiffener spacing	in
b'	-	center to center spacing between dual tire on a gear	
b''	-	center to center spacing between dual patches	in
b_e	-	effective width of deck plating	in
CG	-	center of gravity of helicopter	
CP	-	center of pressure of sail area	
C_o	-	deck function coefficient	
C_1	-	non-dimensionalized bending moment coefficient of plating	
c	-	center to center spacing of dual tires on a gear	in
d	-	depth of stiffener or beam	in
E	-	modulus of elasticity	ksi
e_S	-	effective stiffener span length factor	
e_B	-	effective beam span length factor	
F_{all}	-	allowable stress of material	ksi
F_b	-	allowable stress of material	ksi
F_D	-	vertical helicopter force due to ship motion	kip
F_F	-	tire friction force	kip
F_L	-	Ship motion force longitudinal to helicopter	kip
F_P	-	RAST system holdown force	kip
F_T	-	Ship motion force transverse to helicopter	kip
F_W	-	wind load	kip
F_x	-	longitudinal ship motion load	kip
F_y	-	transverse ship motion load	kip
F_z	-	vertical ship motion load	kip
F_Y	-	yield strength of material	ksi
f_P	-	calculated bending stress in plating	ksi
f_{SB}	-	calculated bending stress in stiffener	ksi
f_{SV}	-	calculated shear stress in stiffener	ksi
I_B	-	moment of inertia of plate-beam section	in^4
I_S	-	moment of inertia of plate-stiffener section	in^4
$K_{1\text{-}12}$	-	ship motion constants from ship specifications	
L_B	-	beam span length	in
L_S	-	stiffener span length	in
M	-	helicopter overturning moment	kip-in

M_C	-	stiffener bending moment correction for elastic supports	kip-in
M_D	-	stiffener bending moment due to dead load of structure	kip-in
M_o	-	stiffener bending moment due to live loading, assumes rigid support	kip-in
Ms	-	total bending moment in stiffener	kip-in
n	-	number of spans over entire length of member	
P	-	patch load	kip
P_b	-	tire bottoming load	kip
P_T	-	tire load	kip
R	-	critical gear reaction, landing load (helicopter characteristic)	kip
R_A	-	auxiliary gear reaction, tail or nose gear	kip
R_M	-	total main gear reaction	kip
R_o	-	beam characteristic load	kip/in
R_1	-	main gear reaction, nearest to tiedown	kip
R_2	-	main gear reaction, farthest from tiedown	kip
r	-	distance between main and auxiliary gears	in
SM_{min}	-	minimum section modulus for stiffener-plate section	in^3
SM_{reqd}	-	required minimum section modulus for stiffener-plate section	in^3
s	-	distance between R_1 and R_2 of main gear	in
T	-	tiedown force	kip
t	-	plating thickness	in
t_f	-	thickness of stiffener flange	in
t_{reqd}	-	required plating thickness	in
t_w	-	thickness of stiffener web	in
V_D	-	stiffener shear due to dead load	kip
V_o	-	stiffener shear due to loading	kip
Vs	-	total shear in stiffener	kip
W_m	-	maximum weight of helicopter	kip
W_p	-	parked weight of helicopter	kip
w_B	-	unit beam weight	lb/ft
w_D	-	dead weight of plating and stiffeners	kip/in
w_f	-	width of stiffener bottom flange	in
w_P	-	weight of plating	lb/ft^2
w_S	-	weight of stiffener	lb/ft
X	-	longitudinal distance from specified center of motion or amidships to helicopter center of gravity	ft
X_G	-	longitudinal distance from helicopter CG to longitudinal center of motion of the ship	in
Y	-	transverse distance from helicopter CG to ship centerline	ft
Y_{TM}	-	transverse distance from centerline to helicopter tiedown in moderate seas	in
Y_{TS}	-	transverse distance from centerline to helicopter tiedown in storm seas	in
Z	-	vertical distance from flight deck to vertical center of motion of the ship	ft
Z_G	-	height of helicopter CG above flight deck	in
Z_{om}	-	equivalent tiedown lever arm in moderate seas	in

Z_{os}	-	equivalent tiedown lever arm in storm seas	in
Z_P	-	height of helicopter CP above deck	
Z_{TM}	-	vertical height above deck to tiedown in moderate seas	in
Z_{TS}	-	vertical height above deck to tiedown in storm seas	in
ϕ_1	-	patch width load distribution factor for stiffener	
ϕ_2	-	plating load distribution factor for stiffener	
ϕ_3	-	dual patch equivalent load factor for stiffener	
ϕ_4	-	beam loading coefficient	
γ_{PS}	-	relative rigidity coefficient of plate-stiffener section	
γ_{SB}	-	relative rigidity coefficient of stiffener-beam section	
η_{xm}	-	longitudinal ship motion factor in moderate seas	
η_{ym}	-	transverse ship motion factor in moderate seas	
η_{zm}	-	vertical ship motion factor in moderate seas	
η_{xs}	-	longitudinal ship motion factor in storm seas	
η_{ys}	-	transverse ship motion factor in storm seas	
η_{zs}	-	vertical ship motion factor in storm seas	
σ_P	-	allowable plate bending stress	ksi
σ_{PR}	-	primary stress from hull girder design	ksi
σ_{SB}	-	allowable stiffener bending stress	ksi
σ_{SV}	-	allowable stiffener shear stress	ksi
Ω_s	-	tiedown angle to deck in storm seas	deg
Ω_m	-	tiedown angle to deck in moderate seas	deg
ψ	-	plating dual patch equivalent load factor	

Glossary

aft	toward, to, or near the stern of the ship
amidship	at or near the midship section of the ship
armament	weaponry aboard the helicopter
athwartship	across the breath of the ship
auxiliary gear	complementary gear to the main gear
bulkheads	a vertical steel partition in a ship
chains	used to anchor down the helicopter to prevent movement
chocks	a heavy fitting placed on the helicopter tires
compartment and access	a plan drawing describing the use and subdivision on a level of the ship
critical gear load	the combination of the gear reaction and loading distribution which creates the worst loading condition
fore and aft	in line with the length of the ship, longitudinal
heave	the up and down motion of a ship along the vertical axis
hull	the body of a ship, includes shell plating, framing, decks, and bulkheads
inboard profile	elevation view of the ship compartments along the ship's centerline
longitudinal	any member, shell, deck, or bulkhead running fore and aft
main gear	the two primary gears of the helicopter
midship	at or near the middle point of a ship's length
non-strength deck	longitudinal deck not contributing to the cross-sectional strength of the hull
load patch	tire contact dimensions with respect to the ship structure
pitch	an oscillatory motion of a ship about the transverse axis
primary stress	resulting stress on the ship structure due to bending of the ship hull from wave action
roll	an oscillatory motion of a ship about the longitudinal axis
sway	the lateral motion of a ship along the transverse axis
scantling plan	structural framing plan
ship motions	the different resulting movements of the ship as a result of impacting waves
significant wave height	the average height of the one third highest waves
stanchions	a pillar or upright post, column
static gear load	the portion of the helicopter load at parking weight without ship motions applied
stiffener	an angled bar, T-section, channel, etc., used to stiffen plating of a bulkhead, deck, or other member
strength deck	longitudinal deck contribution to the cross-sectional strength of the hull
surge	the fore and aft motion of a ship along the longitudinal axis
tiedown force	equivalent force of all the applied tiedowns on a helicopter
tire contact	length and width of the tire as a result of the helicopter load
transverse	athwartship, direction across the breath of the ship
transverse frame	athwartship members forming the ship's cross-section
yaw	oscillatory motion of a ship about the vertical axis