Drilling Torque and Drag Application

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____

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May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMMAD ZAFARUDIN BIN JAFFIR

ABSTRACT

The drastic increases of the extended-reach wells since 1990s help emerges the drilling torque and drag application which is very useful in predicting the torque and drag during drilling operation. This application helps engineering team to plan extended-reach wells in more aggressive manner since it's reduce serious drilling risk such as buckling, pipe failures and box swelling.

Although there are a lots of application developed to help users predict the drilling torque and drag for a drilling operation, however this did not help users in understanding the underlying process and algorithm behind the application that they are using. In the event of drilling, users will be unaware of how torque and drag prediction is done and how it is could effects the whole operation. This will give some difficulty to the users to calibrate the data to suit the well condition.

Therefore this project is proposed to be conducted in developing a similar drilling torque and drag prediction application for educational purpose. This application is not intended to replace any commercial application in the market but most of it purposes is only to expose and assist the users about the fundamental of drilling torque and drag prediction in a drilling operation.

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CHAPTER 1:
INTRODUCTION

1.1 Project Background

Drilling torque and drag is very important to be determined in planning a well especially an extended-reach well. If the torque and drag is not taken into considerations in planning a well, there will be a serious drilling risk throughout the operation. Therefore, drilling torque and drag is done to help minimize the risk. However since the calculation need to be calculated is complex, application were used and the prediction process become much easier.

1.2 Problem Statement

Since the development of the fundamental torque and drag model by Johancsik, Friesen and Dawson in 1984, there were also several works by other authors which had lead to development of numerous application that enable users to predict drilling torque and drag forces experienced to a well which is still in its planning phase (McCormick, Frilot & Chiu, 2011, p.1-2).

Although there are many application in the industry that is been used to predict the torque and drag in drilling operation, however not many users know the underlying process and equation in the application. Such act makes users know less on the fundamental of the drilling torque and drag calculation. In the event of operation, if the fundamental of drilling torque and drag calculation is not understand, this could lead to any materials and mechanical failures due to uncontrolled torque and drag thorough out the drill string, Therefore, application with fundamental reasoning on how and why the torque and drag of a drilling operation is generated should be developed. With this, it helps the users to understand underlying process of drilling torque and drag prediction behind the application.

1.3 Objectives of Study

The objectives of this project are:

1. To analyze drilling torque and drag model available to be used as the working work frame to predict the drilling torque and drag before or during a drilling operation.
2. To develop a working application in Microsoft Excel using Visual Basic Application (VBA) based on the drilling torque and drag model which is suitable to be used in the application.

1.4 Scopes of Study

For this project, the scopes of study involved throughout this project are:

1. The study involved only in the developing of drilling torque and drag application. The purpose is not to replace the available software in market but merely on educational purposes only.
2. The bit performance in term of Rate of Penetration (ROP) of a drilling operation however will not be included in the study.
3. The torque and drag will only include the drilling torque and drag of a 2 dimensional (2D) well geometry.

CHAPTER 2:
LITERATURE REVIEW

2.1 Introduction

Since the inception of extended-reach drilling (ERD) in the oil and gas industry, the number of wells that used this method to produce oil reserved which is normally uneconomically to be produced by using conventional wells, increased drastically since 1990s (Mason & Judzis, 1998). This is because any oil reserves are accessible from available oil rig on site and elimination of high capital cost is achievable. However, according to Aarrestad and Blikra (1994), there are several limitations to the horizontal and inclination displacement of the operation, but the industry focussed most on drilling torque and drag. Furthermore, the ERD wells generally have much higher probability to encounter drilling problems than the conventional wells according to Mason & Judzis (1998).

The drilling problems are most likely to be resulted by unregulated torque and drag throughout the drilling operation. Those drilling problems include serious drilling operation risks such as buckling, pipe failures, box swelling and the inability to get liners and casing to total depth (TD). Therefore, an accurate prediction of drilling torque and drag forces, using the software modelling has become a normal and important process during a well's planning phase in order to overcome such drilling problems (McCormick et al, 2011). Furthermore, specific design of the drill string that suits the drilling torque and drag of the particular wells could be designed (Johancsik et al, 1984).

These in fact will ensure the feasibility of the well planned to be drilled at the certain location. However, in prediction of drilling torque and drag for challenging or complex wells, application would be used since computer can do repeated and lengthy calculation (Mason & Chen, 2007). However, the present of this application had made users know less or nothing regarding the whole process of drilling torque and drag prediction. This will become problem in the future where the drilling process has been started and users are unaware of the factors affecting the torque and drag of the drilling operations.

Therefore, a new simple and easy application will be developed to help ease the user in order to predict the torque and drag of a drilling operation. In order to have an accurate drilling torque and drag prediction, a valid mathematical model should be used to have the accurate result on the torque and drag generated. The model will be discussed in next section of this chapter.

2.2 Brief Description on Drilling Torque and Drag

Johancsik et al. (1984) refer the torque as "the moment required to rotate the pipe." This rotational force is required and generated by equipment on the oil rig to oppose the resistance to rotation. The drilling torque magnitude can be measured by multiplying the perpendicular component of the force applied by the radius of the drill string (Agbaji, 2009). The equation is as follows:

$$\tau = F_R \times r \qquad (1)$$

where, τ is the torque calculated,

F_R is the perpendicular component of the force applied, and

r is the radius of the pipe.

However, according to (Payne & Abbassian, 1997), the above equation is not completed to be used in estimating the torque value of the total surface torque. Therefore, the following equations are used and the total surface torque could be estimated. The equation includes each torque components available in a drill string:

$$\begin{aligned} Total\ Surface\ Torque &= Frictional\ String\ Torque + Bit\ Torque + Mechanical\ Torque \\ &\quad + Dynamic\ Torque \end{aligned}$$

Note that mechanical torque in the equation above. The mechanical torque is the torque exerted by the equipment on the rig floor and due to friction along the drill string, the torque at the bit will be difference.

While drag is the contact force between drill string and wellbore wall, and the magnitude of the force depends on the weight and tension of the drill string (Wu & Hareland, 2012). In addition, drag also can be described as the force that opposes the movement of the drill string (Agbaji, 2009) which also reduce the surface torque transmitted to the bit (Mitchell, 2008). This force will be increased with increased of hole inclination and curvature due to gravity effect and compression that pushing the drill string against the lower side of the borehole and due to drill string tension that pulling up the drill string to the high side of the borehole (Aarrestad and Blikra, 1994).

2.3 Drilling Torque and Drag Modelling Fundamental

The development of the extended-reach drilling wells is inevitable since it can save cost and reduce the number of offshore platforms on an oilfield to be developed (Mirhaj et al, 2011). However, the only limitation of this operation is the drilling torque and drag which will create drilling problem if not managed properly. Therefore, torque and drag (T&D) modelling is introduced to help predict and hence prevent drilling problems that might occur during the drilling process (Mirhaj et al, 2011).

According to Mirhaj et al. (2011), the original torque and drag model is started by Johancsik et al. (1984) and then formalize by Sheppard et al. (1987). In the earlier model developed by Johancsik, several assumptions are made up and they are:

1. Torque and drag are caused entirely by sliding friction forces which result from contact of the drill string with the wellbore.
2. The magnitude of the sliding friction force is affected only by two factors. There are; normal contact force and the coefficient of friction between the contact surfaces.

3. Only effects of gravity on the pipe and the effects of tension acting through curvatures in the wellbore are considered to contribute to normal force.
4. Only a single characteristic friction coefficient representing average conditions in a particular wellbore.
5. Pipe bending which may contribute small normal forces are not taken into consideration in developing the drilling torque and drag model.

Most of the drilling torque and drag model are using the soft string model. According to McCormick et al. (2011), a soft string model assumes that the entire drill string lies on wellbore, and the stiffness of the drill string is not taken into consideration in developing the torque and drag model. In contrast to the soft string model, the stiff string model of the torque and drag model also been developed. In stiff string model, the actual stiffness which is the bending moment in the tubular and radial clearance in the wellbore of the string is taken into considerations while developing the model (McCormick et al, 2011).

However, in the Johancsik work of developing drilling torque and drag model, Johancsik assume the model to be soft string model. The calculation started at the bottom of the drill string and continued upward. The drill string is divided into short elements of similar length and each element contributes small increments of axial and torsional load.

Johancsik stated that the first step in drilling torque and drag calculation is to calculate the normal force of each element to calculate the increment for an element of the drill string. Therefore the magnitude of the normal force is:

$$F_n = [(F_t \Delta\alpha \sin\theta)^2 + (F_t \Delta\alpha + \sin\theta)^2]^{1/2} \quad (2)$$

where, F_n is the net normal force acting on element, lbf [N],

F_t is the axial tension acting at lower end of element, lbf [N],

$\Delta\alpha$ is the increase in azimuth angle over length of element, degrees [rad], and

θ is the inclination angle at lower end of drill string element, degrees [rad].

The above equation later is used to derive the equation increment which is used for drag calculations:

$$\Delta F_t = W \cos\theta \pm \mu F_n \tag{3}$$

where,	F_t	is the axial tension acting at lower end of element, lbf [N],
	W	is the buoyed weight of drill string element, lbf [N],
	θ	is the inclination angle at lower end of drill string element, degrees [rad],
	μ	is the sliding friction coefficeient between drill string and wellbore, and
	F_n	is the net normal force acting on element, lbf [N].

Where the plus and minus sign indicate the pipe movement direction. Whereas torsion increment which is used for torque calculation is as follows:

$$\Delta M = \mu F_n \tag{4}$$

where,	ΔM	is the increase in torsion over length of element, ft-lbf [Nm],
	μ	is the sliding friction coefficeient between drill string and wellbore, and
	F_n	is the net normal force acting on element, lbf [N].

Later Sheppard et al. (1987) puts the Johancsik model into a standard differential form and because of the simplicity and being user friendly, it has been extensively used in the field and industry applications (Mirhaj et al, 2011). In Johancsik model, only tension is take into account while mud pressure is neglected (Sheppard et al, 1987). Therefore, Sheppard develop a new model and include the mud pressure into account which avoids confusion over the location of the neutral point and the influence of buoyancy forces on curved pipe sections. Sheppard assumes that the drag force at any point of the drill string is proportional to the side force acting there.

$$\sigma_e(s) = \sigma(s) + p(s)A(s) \tag{5}$$

where,	$\sigma_e(s)$	is the effective tension at s, ft-lbf [Nm],
	$\sigma(s)$	is the tension at s, lbf [N],

$p(s)$ is the mud pressure at s, psi [kPa], and

$A(s)$ is the pipe cross-sectional area at s, ft^2 [m^2].

Later, the tension profile may then be derived from the σ_e profile, which is given by:

$$\frac{\partial \sigma_e}{\partial s} = W_b \cos\theta(s) \pm K \left\{ \left[\sigma_e \frac{\partial \theta}{\partial s} + W_b \sin\theta(s) \right]^2 + \left[\sigma_e \frac{\partial \beta}{\partial s} \sin\theta(s) \right]^2 \right\}^{1/2} \quad (6)$$

where, W_b is the buoyed weight per unit length.

Noted that $+K$ term applies in cases of drill string tripping out, while $-K$ applies in cases of tripping in. In cases of a rotating drill string, the tension profile is derived from Eq. 6 by substituting$K = 0$. The + sign in front of the W_b means that parameter s running from the bit up the drill string.

From the profile derived from Eq. 6, the drag profile $F(s)$ is given by Sheppard as:

$$F(s) = K \left\{ \left[\sigma_e(s) \frac{\partial \theta}{\partial s} + W_b \sin\theta(s) \right]^2 + \left[\sigma_e(s) \frac{\partial \beta}{\partial s} \sin\theta(s) \right]^2 \right\}^{1/2} \quad (7)$$

Both of the model, Johancsik and Sheppard model divided the drill string into short elements and the drilling torque and drag calculation is done to each element of the drill string since most of the element would have different inclination with each other and the torque and drag will be different at each element. This calculation is done from the bottom of the drill string and each calculation contribute to the torque and drag increment and the result will contribute to torque and drag increment up the drill string. As the result, total torque and drag could be obtained.

However, Aadnoy in 2008 developed a generalized friction model which is could be used for different wellbore geometry but with only using several equation. The following is the summary of the simplified equations developed by Aadnoy.

Drag in a bend is given by

$$F_2 = f(\alpha_2) + \left(F_1 - f(\alpha_1)\right) \times e^{k.\mu(a_2 - a_1)} \quad (8)$$

where:

$$f(\alpha) = \frac{w.R}{1+\mu^2}\{(1-\mu^2)\sin\alpha - 2k.\cos\alpha\} \quad (9)$$

and $k = 1$ if the string contacts inner side while $k = -1$ if the string contacts outer side.

Torque if static string:

$$T = r.\mu|(F_1 - wR\sin\alpha_1).(\alpha_2 - \alpha_1) - 2w.R.(\cos\alpha_2 - \cos\alpha_1)| \quad (10)$$

Torque in a bend if there is simultaneous hoisting and rotation:

$$T = r.\mu\left|\left(F_1 - f(\alpha_1)\right)\frac{1}{k\mu}\left(e^{k\mu(\alpha_2-\alpha_1)} - 1\right) + f_{Lin}(\alpha_2) - f_{Lin}(\alpha_1)\right| \quad (11)$$

where:

$$f_{Lin}(\alpha) = \frac{-2.w.R}{1+\mu^2}(\cos\alpha + k.\mu.\sin\alpha) \quad (12)$$

For straight section the above equations reduces to:

$$F_2 = F_1 + w.\Delta s(\pm\mu\sin\alpha + \cos\alpha) \quad (13)$$

$$T = r\mu|w\Delta s\sin\alpha|$$

where,

F_1	is the force at the clockwise end of the bend,
F_2	is the force at the anticlockwise end of the bend,
α_1	is the wellbore angle at the clockwise end of the bend,
α_2	is the wellbore angle at the anticlockwise end of the bend,
μ	is the friction coefficient between the pipe and the hole,
w	is the unit pipe weight, including buoyancy,
r	is the radius of the pipe, and
R	is the radius of the build up section.

By using the above equation, the bottom hole assembly do not required to be divided into small parts and the torque and drag could be estimated directly in each section.

CHAPTER 3:
METHODOLOGY

3.1 Project Activities

In conducting this project several methodologies has been lined out to help in the progress of this project. The methodologies involve in conducting this project are:

1. Analyze mathematical model of drilling torque and drag available in the research paper, journal, textbook or any resource information.
2. Construct the application algorithm based on the suitable mathematical model analyzed.
3. Develop the application by using the Visual Basic Application (VBA) available in the Microsoft Excel.
4. Test the completed application with the site data or simulation to validate the workability of the application.

3.2 Key Milestone

The following table is the proposed key milestone for this project:

Table 1: Proposed Key Milestone in FYP 1.

NO.	WORK/WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								Mid-Semester Break							
2	Preliminary Research Work															
5	Submission of Extended Proposal															
6	Proposal Defence															
7	Project work continues															
8	Submission of Interim Draft Report															
9	Submission of Interim Report															

Table 2: Proposed Key Milestone in FYP 2.

NO.	WORK/WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■	Mid-Semester Break								
2	Submission of Progress Report							■									
3	Project Work Continues									■	■	■	■	■			
6	Pre-Sedex											■					
7	Draft Report												■				
8	Dissertation (Soft Bound)													■			
9	Technical Paper													■			
10	Oral Presentation														■		
11	Project Dissertation (Hard Bound)																■

The following are the proposed flow chart that will be used throughout this project:

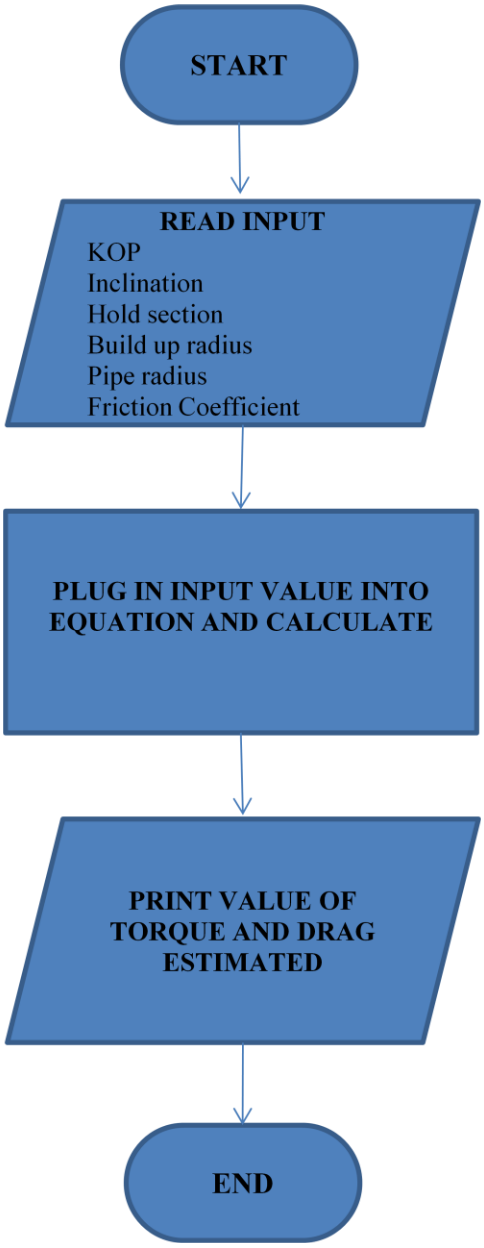


Figure 1: Application Flow Chart

CHAPTER 4:
RESULT AND DISCUSSIONS

4.1 Data Gathering And Analysis

In data gathering and analysis, the input data which will be are based on the data provided by Aadnoy (2008). The data provided are the input data which is created to be used to test the generalized torque and drag model developed. The data are as follows:

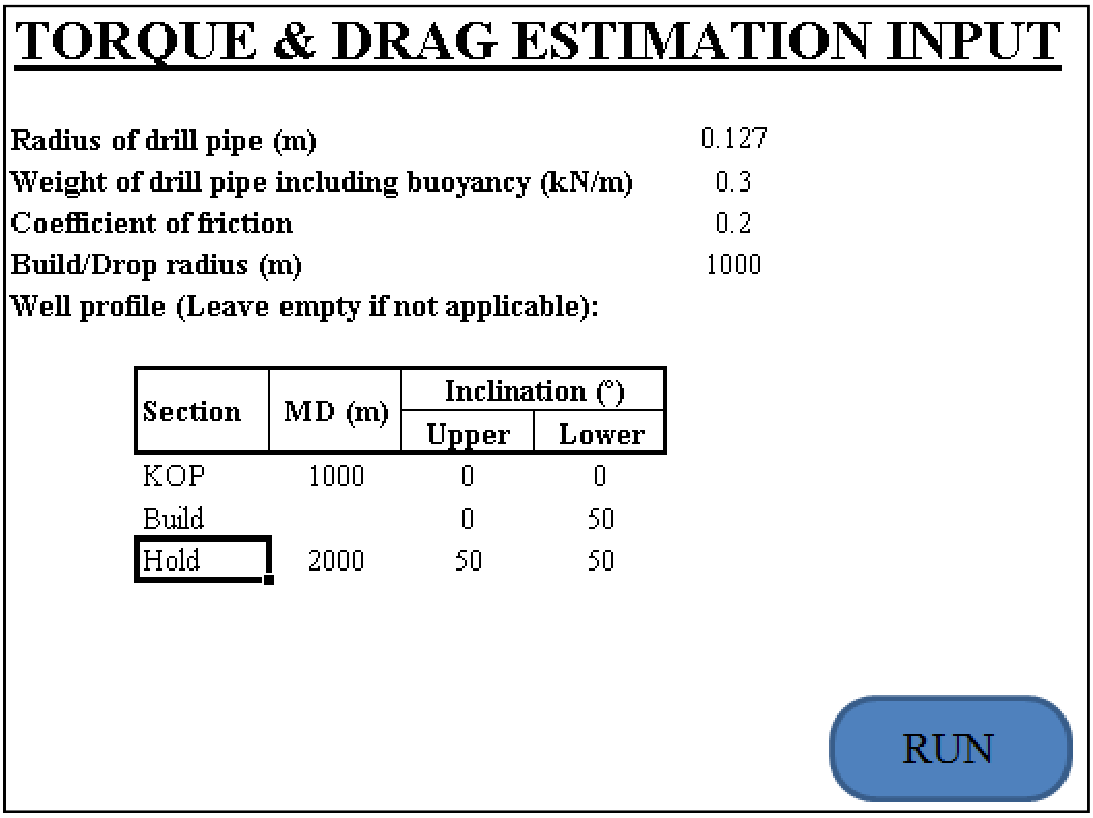
Table 3: Input data for testing.

Vertical	1000 m
Inclination	50°
Hold section MD	2000 m
Build-up radius	1000 m
Pipe radius	5”
Pipe unit weight including buoyancy	0.3 kN/m
Coefficient of friction	0.2

This input data will be used to generate the drilling torque and drag prediction, later will be compared and analyze to get the developed application validity.

4.2 Torque and Drag Prediction Application

The following picture is the input section of the application.



TORQUE & DRAG ESTIMATION INPUT

Radius of drill pipe (m)	0.127
Weight of drill pipe including buoyancy (kN/m)	0.3
Coefficient of friction	0.2
Build/Drop radius (m)	1000

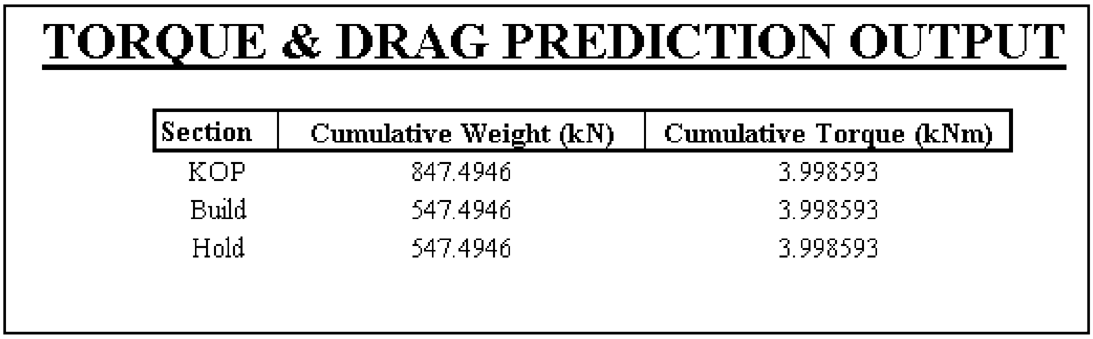
Well profile (Leave empty if not applicable):

Section	MD (m)	Inclination (°)	
		Upper	Lower
KOP	1000	0	0
Build		0	50
Hold	2000	50	50

RUN

Figure 2: Input section of the application.

After user input the above data, the user will press run to produce the output of the torque and drag prediction data. The following figure is the output section of the application:



TORQUE & DRAG PREDICTION OUTPUT

Section	Cumulative Weight (kN)	Cumulative Torque (kNm)
KOP	847.4946	3.998593
Build	547.4946	3.998593
Hold	547.4946	3.998593

Figure 3: Output section of the application.

For future works, the drilling torque and drag application will be developed to enable data analysis. The application algorithm will be constructed and the application working process will be following that algorithm. User interfaces of the application also will be developed to aid and make ease of the usage of the application to the user. Later, the application will be tested and the application data validity will be compared.

CHAPTER 5:
CONCLUSIONS

5.1 The Conclusions

In conclusions, throughout the project progress, the objective is slightly achieved although the project activity is still in progress and the key milestone is not in the track. As been discussed in the Literature Review, the drilling torque and drag model for this project should be analyzed and understood into deeper level.

This is because the mathematical models available are derived from Johancsik and Sheppard is too much because of its simplicity and being user friendly. However, both model developed yet a good model because it is used by most of the drilling torque and drag software available in the market.

5.2 Future Works

In the future, this application can be expanded to include well trajectory builder which enable the user to predict the torque and drag of any well geometry. As stated in this project scope of study, the well geometry involves in developing this application is the build and hold well trajectory. This scope of study, have limit the usage of this application on others well trajectory in the industry and such limitation is not promoting the usage of this application in much wider usage.

The others recommendation could be suggested in the future works of this application are to include the ability of the application to suggest the best Rate of Penetration (ROP) of a drilling operation. With this new improvement, the user is made aware that their ROP choice is favourable for torque and drag limitation of the drilling operation.

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APPENDIX

The program source code is as follows:

```
Option Explicit

Dim PR As Double 'pipe radius
Dim PW As Double 'pipe weight
Dim CF As Double 'coefficient of friction
Dim R As Double 'build radius
Dim a As Integer 'angle
Dim a1 As Integer 'angle at the clockwise end of bend
Dim a2 As Integer 'angle at the anticlockwise end of bend
Dim k As Integer 'constant for drillstring movement
Dim F1 As Double 'force at clockwise end of drillstring
Dim MD As Integer 'along hole depth
Dim NSC As String 'name of the section
Dim n As Integer 'count of loop
Dim SC As Integer 'count of section
Dim RNI As String 'range name of input
Dim RNO As String 'range name of output
Dim CT As Double 'cumulative torque

Function f(PW, R, CF, k, a)
    f = (PW / (R * (1 + (CF ^ 2)))) * ((1 - (CF ^ 2)) * Sin(a) - 2 * k * CF * Cos(a))
End Function

Function DragInBend(k, CF, a2, a1, R, PW)
    DragInBend = f(PW, R, CF, k, a2) + (F1 - f(PW, R, CF, k, a1)) * Exp(k * CF * (a2 - a1))
End Function

Function TorqueStaticString(PR, CF, F1, PW, R, a1, a2)
    TorqueStaticString = PR * CF * Abs((F1 - PW * R * Sin(a1)) * (a2 - a1) - 2 * PW * R * (Cos(a2) - Cos(a1)))
End Function

Function flin(PW, R, CF, k, a)
    flin = (-2 * PW * R / (1 + CF ^ 2)) * (Cos(a) + k * CF * Sin(a))
End Function
```

```
Function TorqueBendNonStatic(PR, CF, F1, PW, R, k, a1, a2)
    TorqueBendNonStatic = PR * CF * Abs((F1 - f(PW, R, CF, k, a1)) * (1 / (k * CF)) * (Exp(k * CF * (a2 - a1)) - 1) + flin(PW, R, CF, k, a2) - flin(PW, R, CF, k, a1))
End Function


Function DragStraight(F1, PW, MD, k, CF, a)
    DragStraight = F1 + PW * MD * (k * CF * Sin(a) + Cos(a))
End Function


Function TorqueStraight(PR, CF, PW, MD, a)
    TorqueStraight = PR * CF * Abs(PW * MD * Sin(a))
End Function



Sub TorqueDragEstimation()


    Worksheets("Torque & Drag").Activate
    PR = Range("F3").Value
    PW = Range("F4").Value
    CF = Range("F5").Value
    R = Range("F6").Value
    SC = 1
    F1 = 0
    CT = 0
    k = 1

    Range("B11").Select

    Do While ActiveCell.Offset(1, 0).Value <> Empty
        ActiveCell.Offset(1, 0).Select
        SC = SC + 1
    Loop

    For n = SC To 1 Step -1
        If ActiveCell.Offset(0, 2).Value = ActiveCell.Offset(0, 3).Value Then
            RNI = "B" & 10 + n
            NSC = Range(RNI).Value
            MD = Range(RNI).Offset(0, 1).Value
            a = Range(RNI).Offset(0, 2).Value

            RNO = "M" & 3 + n
            Range(RNO).Value = NSC
            Range(RNO).Offset(0, 2).Value = DragStraight(F1, PW, MD, k, CF, a)
            Range(RNO).Offset(0, 5).Value = CT + TorqueStraight(PR, CF, PW, MD, a)
```

```
        F1 = Range(RNO).Offset(0, 2).Value
        CT = Range(RNO).Offset(0, 5).Value

    Else
        RNI = "B" & 10 + n
        NSC = Range(RNI).Value
        a1 = 360 - Range(RNI).Offset(0, 3).Value
        a2 = 360 - Range(RNI).Offset(0, 2).Value

        RNO = "M" & 3 + n
        Range(RNO).Value = NSC
        Range(RNO).Offset(0, 2).Value = DragInBend(k, CF, a2, a1, R, PW)
        Range(RNO).Offset(0, 5).Value = CT + TorqueBendNonStatic(PR, CF, F1, PW, R, k, a1, a2)

        F1 = Range(RNO).Offset(0, 2).Value
        CT = Range(RNO).Offset(0, 5).Value

    End If

  Next n

End Sub
```